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# A
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# CHEMISTRY,

## ON THE BASIS OF THE NEW SYSTEM.

BY

EDWARD L. YOUMANS, M. D.,

AUTHOR OF THE "HAND-BOOK OF HOUSEHOLD SCIENCE."

*REWRITTEN AND REVISED. WITH MANY NEW ILLUSTRATIONS.*

NEW YORK:
D. APPLETON AND COMPANY,
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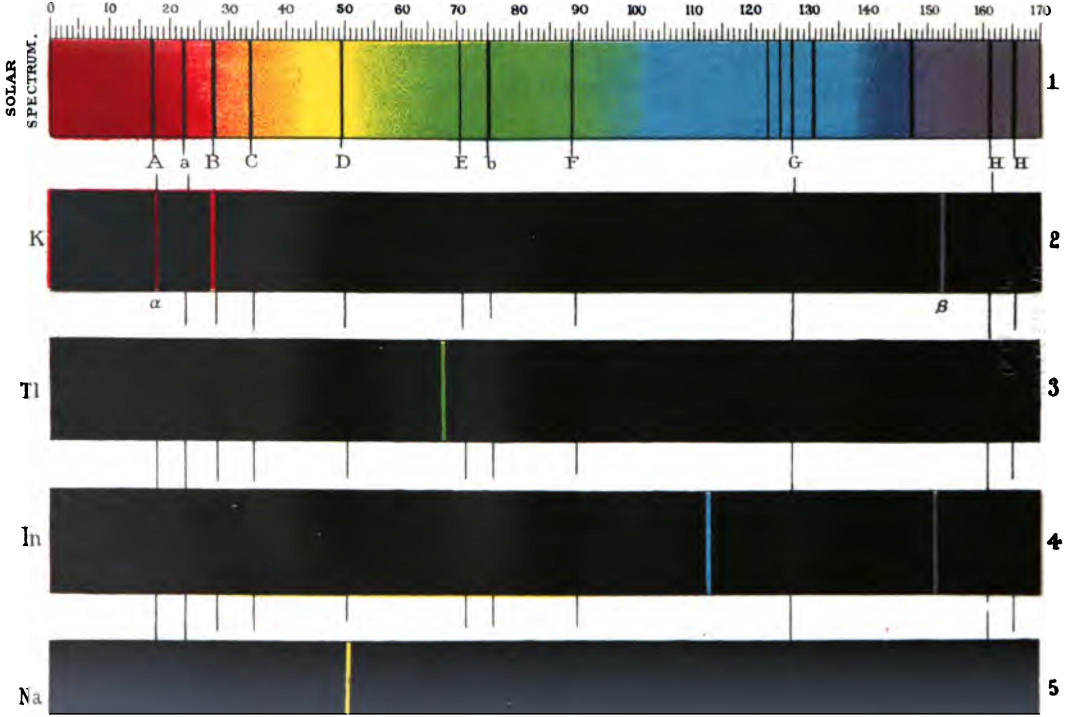
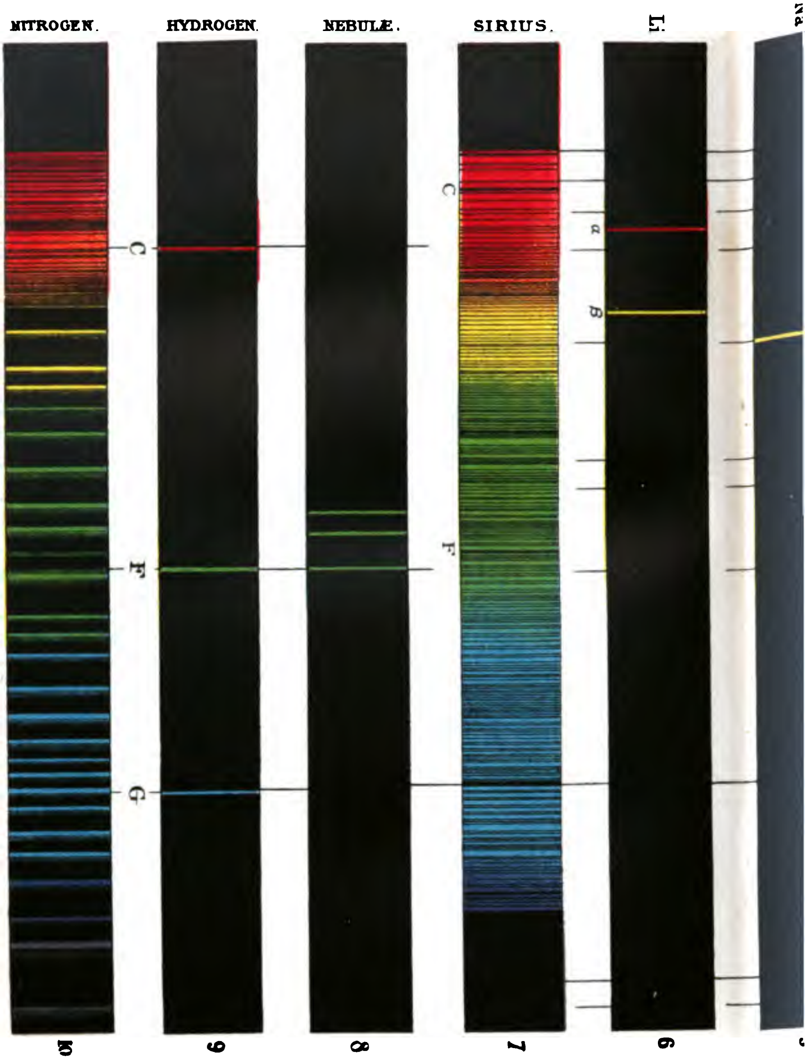
# SPECTRA OF THE STARS AND NEBULÆ, COMPARED WITH THE SOLAR SPECTRUM, AND THE SPECTRA OF SOME OF THE NON-METALLIC ELEMENTS.

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# PREFACE.

THE "Class-book of Chemistry," first published in 1852, was rewritten in 1863, and has now been again thoroughly revised, so as to bring it into harmony with the latest views, and adapt it more perfectly to the wants of those for whom it was prepared. The first edition represented the state of chemistry as it prevailed at the time of publication, and had been long established; but the revised edition, though adhering to the old theories, recognized that they were undergoing important modifications. These modifications have been long in progress, and having at length issued in a new system of chemical doctrine, which has been generally accepted by chemists, it has been adopted in the present volume, and explained and applied as fully as the plan of the work will allow. The present position of the science is, therefore, of special importance in relation to its exposition.

There can be no question that the new theories mark an important step in the progress of chemistry. They harmonize a wider range of facts, and give us a more consistent philosophy of the subject, than the theories they supersede. Yet they are far from being complete. The present situation is the proverbially uncomfortable one of transition; the old house having ceased to be habitable, while the new one is unfinished. Prof. A. Crum Brown, of the Edinburgh University, in a late address before the British Association, well stated the present attitude of chemical theory in the following words:

> "It is impossible to make a certain forecast: looking back, we see a logical sequence in the history of chemical speculation; and no doubt the next step will appear, after it has been taken, to follow as naturally from the present position. One thing we can distinctly see—we are struggling toward a theory of chemistry. Such a theory we do not possess. What we are sometimes pleased to dignify with that name is a collection of generalizations of various degrees of imperfection. We cannot attain to a real theory of chemistry until we are able to connect the science by some hypothesis with the general theory of dynamics."

This view of chemical science, as a body of thought in process of development, more perfect at present than ever before, but still imperfect in relation to the future, should not now be lost sight of. It shows both the reason and necessity of change, reconciles difficulties, and enables us rightly to estimate the value of preceding systems, which, although now displaced, were essential conditions of chemical advancement. We are not to regard past theories as mere exploded errors, nor present theories as final. The living and growing body of truth has only moulted its old integuments in the progress to a higher and more vigorous state. It is certainly desirable that this complexion of the subject should be recognized in its presentation to ordinary students. Practical text-books, intended for mastering the subject experimentally, must, of course, be much confined to existing facts and the principles by which they are now interpreted; but books designed to present the science in its general relations for popular educational uses should not overlook the considerations suggested in the above-quoted passage. In this volume, therefore, I have aimed to preserve somewhat the transitional aspect of the subject, so that the "New Chemistry" may neither be regarded as an ingenious device of yesterday, nor as a finality to be acquired with no expectation of further improvement.

To prevent misconception respecting the claims of this class-book, it is necessary to repeat what was said in the Preface to the preceding edition. It is not designed as a manual for special chemical students. It aims to meet the wants of that considerable class, both in and out of school, who would like to know something of the science, but who are without the opportunity or the desire to pursue it in a thorough experimental way. Some acquaintance with the subject is now required as a part of every good education; but books designed for laboratory use, and abounding in technical details, are ill-suited to those who do not give special and thorough attention to the subject. I have here attempted to furnish such an outline of the leading principles and most important facts of the science as shall meet the needs of the mass of students in our high schools, seminaries, and academies, who go no further with the subject than to study a brief text-book, with the assistance perhaps of a few lectures, and the observation of some accompanying experiments.

The present edition has been much reduced in compass, both by the use of larger type and fewer pages, and it has thus been brought into more manageable limits for school-use. Much new matter has, however, been introduced under various heads. The rapid development of spectrum analysis since the former edition was published, and the great interest of the subject, have led to considerable expansion of that topic. The treatment of the chemistry of light is also amplified, and the chapter on theoretical chemistry explaining the new system is made as full as the proportions of the volume will allow. Tables of the French system of weights and measures are appended for the use of those who desire to employ it. As the progress of investigation is constantly bringing physics and chemistry into closer relations, the division of chemical physics has been retained, although the text has been much reduced.

Such a class-book can, of course, have little value for the usual purposes of reference. It must be but a brief compend of general principles and descriptions of some of the most important substances, and is not to be judged by the fullness of its details. Such are already the vast proportions of the science, and such the enormous rapidity of its growth, that nothing less than works of encyclopedic scope have value for general consultation. Watts's invaluable "Dictionary of Chemistry," with its five volumes averaging a thousand closely-printed pages, has already a thousand-paged supplement; and it would require such a volume every year adequately to report the progress of the science. The class-book should be supplemented by some such ample treatises in every school-library.

I have to acknowledge especial indebtedness in preparing the chapter on theoretical chemistry to the admirable volume of Professor J. P. Cooke, entitled "The New Chemistry"—one of the finest pieces of exposition in the language. It is a book that every chemical teacher should study, and I would moreover earnestly recommend them to place it in the hands of their classes, and have them go carefully through it. No other work that I know of can put them in such thorough possession of the later stand-points of chemical study.

To many teachers and superintendents of schools who have been anxious for the appearance of this revised edition of the class-book, my apologies are due for broken promises and a delay in publication that may well have seemed without excuse. I have only to plead that the volume would have been issued long since but for the failure of my eyesight from overwork. I have been greatly aided in this revision by my excellent friend Professor Charles Froebel; and I have also to thank another friend, Miss Mary E. Shaw, for efficient assistance in seeing the book through the press. That errors may have crept in is probable, but I think they will not be found serious, and shall be glad to have any inaccuracies pointed out for correction in future editions.

E. L. Y.

NEW YORK, *June*, 1875.

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# THE

# CLASS-BOOK OF CHEMISTRY.

---

## INTRODUCTION.

**1. What is meant by Science.**—Science is a knowledge of the phenomena of Nature. By Nature is understood that vast and diversified array of things which exists around us, and of which we form a part. The term *phenomena* means literally appearances, but it is applied to all the objects and actions of the natural world which we can recognize in any way. Thus we speak of celestial phenomena and material phenomena, the phenomena of sound and the phenomena of thought. Natural things are constantly undergoing changes. These changes do not take place by chance or irregularly, but with inflexible uniformity. The uniformities of change are termed *laws*, and the whole system of laws is known as the *Order of Nature.* It is, therefore, the object of science to discover and explain the laws and order of natural phenomena.

**2. The Test of Science.**—Knowledge grows; ordinary, loose information, is gradually developed into the more perfect form of science. The qualities of things are first studied, then their quantities; first there is certainty, then exactness. As the laws of Nature are regular, in proportion as we understand them we can foresee their effects. In the simplest science, astronomy, we can predict effects thousands of years to come. In the more complicated sciences, prediction is less complete, and, as each science is perfected, it gives larger foresight. *Prevision*, or the power of seeing beforehand what will take place in given circumstances, is, therefore, the most perfect test of science.

**3. Matter and Force.**—The phenomena of Nature present themselves under two different aspects called matter and force. Whatever occupies space, or has weight, is termed *matter*, and different kinds and portions of it are called substances, or bodies. The properties of matter are the characters by which its different kinds are known. Thus iron is known by one set of properties, glass by another, and air by another. A fundamental property of matter is its indestructibility. There is no evidence that, in the course of Nature, or by the operations of art, any particle of matter either comes into existence, or is annihilated. But, while matter itself remains imperishable, all its forms are mutable. Every substance is capable of being altered in form or properties.

Whatever acts upon matter, to change it, is called *force*. Thus the force of gravity causes bodies to change position or fall to the earth; the force of heat causes metals to melt, or change form, and chemical force corrodes them, or changes their metallic nature. Different kinds of force are convertible into each other, but it is now believed that force, like matter, is essentially indestructible, and only changes its form. The total amount of energy in the universe, by which matter is changed, is held to be unalterable.

**4. Physical Properties and Changes.**—Those various familiar characters by which bodies are known—as color, weight, hardness, temperature—are termed physical properties; and those various alterations of form and quality, which bodies undergo without destroying their distinctive characters, are termed physical changes. Thus iron may be cut, melted, or magnetized, but it still remains iron.

Gravity, cohesion, heat, light, electricity, and magnetism, are the forces chiefly concerned in modifying physical properties, and are therefore known as physical forces.

**5. Chemical Properties and Changes.**—But matter is capable of undergoing changes by which its distinctive characters are destroyed. Thus bright iron, when exposed to damp air, is converted into a brown rust. When vinegar and lime are brought together, they combine, losing their properties, and producing a new and different substance. When wood is heated, in the absence of air, it is changed to a black, brittle mass; if heated in the presence of air, it is changed to invisible gases and ashes. These are examples of the chemical changes of matter.

Chemistry divides all substances into two kinds, simple and compound. Compound bodies are such as can be separated or decomposed into simpler parts; simple bodies, on the contrary, are such as cannot be thus decomposed. Water is a compound, and can be separated into two invisible gases; but neither of these can be again resolved into different kinds of matter; they are, therefore, ranked as simple bodies, or elements. Chemical science treats of the composition of matter, of the nature and properties of its elementary parts, of the compounds which may be formed from them, and of the laws by which combination and decomposition are governed.

**6. Chemical Physics.**—No chemical change can occur without being accompanied by some kind of physical change. So intimately are the forces of Nature connected, that the disturbance of any one is certain to involve a variety of effects. Physical forces and conditions have so powerful an influence over chemical actions, that some knowledge of them is indispensable to the chemical student. Accordingly, under the title of "Chemical Physics," we shall first treat briefly of those physical agencies which are most intimately connected with the subject of chemistry.

# PART I.

# CHEMICAL PHYSICS.

## CHAPTER I.

## GRAVITY.

### § 1. *Absolute Mass, Volume, and Weight.*

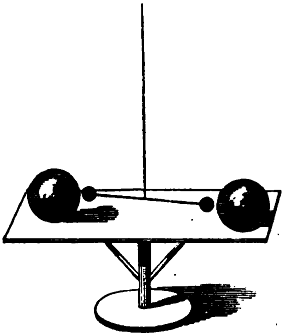
**7. The Measurement of Matter.**—The science of chemistry is based upon numerical laws, and the chemist is almost always occupied in investigating quantities, amounts of matter, or amounts of change; and this is done by the operations of weighing and measuring. The amount of any material body occupying space is termed the *mass*, and the quantity of space so occupied, the *volume* or bulk of that body. The process by which the volume of any body is determined is termed *measurement*, and the instruments used for this purpose are called *measures of capacity.* They consist of vessels of various shapes, always inclosing the same or multiples of the same amounts of space. The units or standard amounts of space to which volumes are referred vary in different countries. For ordinary purposes, gallons, quarts, pints, cubic inches, cubic feet, and cubic yards, are most commonly used with us, but, in making scientific investigations, the *metrical* scale, also called the decimal or French scale, of measures is now almost universally employed.

**8. Metrical Measures.**—The basis of the metrical system of measures is the linear *metre*, a length equal to 39.368 American inches. To the decimal divisions of this length, names composed of the word metre and a prefix formed from Latin numerals have been given; and the decimal multiples of the same standard are similarly made up by engrafting Greek numerals. The following are the designations: one-tenth of a metre is called one decimetre; one-hundredth, one centimetre; one-thousandth, one millimetre; and ten metres are called one dekametre, one hundred one hectametre, one thousand one kilometre, etc.

The cubic decimetre, or *litre*, is the unit most generally used as the standard of volume, but the cubic centimetre is also very often employed. To compare these measures with one more familiar, it may be remembered that one litre is equal to 61.016 cubic inches or 2.113 pints.

**9. Gravity.**—The attractive force by which bodies are drawn to the surface of the earth is called gravity. It acts between masses of matter of every kind, and at all distances. The mutual attraction of masses of matter has been thus illustrated: A pair of leaden balls, two inches in diameter, were attached to the ends of a rod, which was suspended in the middle by a fine wire (Fig. 1). Two other balls of lead, a foot in diameter, were placed upon a revolving platform, and, when the larger and smaller balls were brought near together, they were mutually attracted, as was shown by the motion of the rod. The force exerted did not exceed the twenty-millionth

FIG. 1.



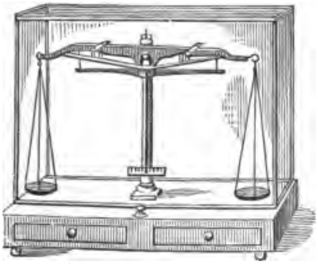
Mutual Attraction of Leaden Balls.

of the weight of the lesser ball, but was sufficient to slightly twist the wire, and give rise to a small oscillatory movement. The force of gravity is proportional to the quantity of matter; that is, if the earth had twice its present mass, its attraction would be doubled, if but one-half its mass, its force would be only half as great. So with any body on the earth, the force with which it is attracted increases or diminishes in exact proportion to its quantity.

**10. Weight.**—If a body, instead of being allowed to fall, is supported, its tendency to descend is not destroyed. It is drawn downward with the same force, but, as it is resisted, and at rest, the force takes the shape of pressure. This downward pressure of bodies is called their *weight.* The weight of a body is the force it exerts in consequence of its gravity, and, as this force depends upon the quantity of matter, it is clear that, if the mass be doubled, the weight will be doubled; if the mass be halved, the weight will be halved. Weights are therefore nothing more than measures of the force of gravity in different objects, and we measure the force to determine the quantity of matter.

**11. The Balance.**—The instruments employed by chemists in weighing are balances. The chemical balance (Fig. 2), used for analysis, consists of an inflexible bar, delicately poised at a point exactly midway between its extremities, from which the scale-pans are suspended. Its beam rests upon a fine edge of hardened steel, which is supported by a flat plate of polished agate. This beam oscillates toward the earth just as the rod in the preceding experiment oscillated toward the larger balls.

FIG. 2.



The Chemical Balance.

**12. Standard Weights.**—The operation of *weighing* consists in estimating the force with which any given body is attracted toward the earth by comparing it with other masses of matter already weighed and marked according to some fixed standard, as Troy, Avoirdupois, or French weight. These standard scales are quite arbitrary, there being no natural starting-point, or unit. The grain-weights were originally grains of wheat. The scales established in this country are capriciously arranged, while the French employ a decimal scale, which, being far more convenient, is almost always used in scientific investigations, and is gradually being adopted by different states and countries as the legal standard for the transaction of ordinary business.

**13. Metrical Weights.**—The French or metrical system of weights is based upon the metrical measures before mentioned. The standard unit of the scale is the weight of one cubic centimetre of pure distilled water at the temperature of maximum density (39°.2 Fahr.). The decimal fractions and multiples of the scale are distinguished by the addition of the same Latin and Greek prefixes already mentioned above, to the name of the unit. This is called the *gramme*, or *gram*. The gramme is equal to 15.432 grains, and the kilogramme to 22.046 pounds avoirdupois. Tables of equivalence of French and English weights are given in the Appendix.

## § 2. *Specific Mass, Volume, and Weight.*

**14. Specific Volume.**—Different bodies of equal weight do not occupy like amounts of space. Though a pound of cork exactly counterpoises a pound of lead, yet the former has a volume forty times greater than the latter. By comparing, therefore, the volumes of different substances with the volume of any one body of equal weight taken as unity, we may obtain their specific volumes.

**15. Specific Weight or Gravity.**—Inversely, also, different bodies of equal volume do not weigh the same. Thus 100 cubic inches

| | Pounds. | Grains. |
|---|---|---|
| Of hydrogen weigh . . . . | | 2.14 |
| Of air " . . . . | | 31 |
| Of water " . . . . . | 3.604 | |
| Of iron " . . . . | 28.11 | |
| Of platinum " . . . . | 75.68 | |

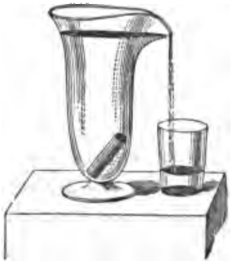
Platinum, the heaviest body we know, is thus nearly a quarter of a million times heavier than an equal bulk of hydrogen, the lightest of known substances.

If we, then, determine, not the absolute gravity of a substance, but its weight compared with another body of equal size, we obtain its relative, or *specific* gravity. Any solid substance when immersed in water displaces a volume exactly equal to its own bulk, and, at the same time, loses a portion of its own weight just equal to that of the volume of water displaced. Water, which is found everywhere upon the globe, and easily purified by distillation, is therefore taken as the unit of comparison for solids and liquids. As variations of temperature alter the bulk of bodies, sp. g. is taken at the standard of 60° Fahr. In the metrical system, the weight of one cubic centimetre of water at 39°.2 Fahr. is equal to one gramme. The weight of one cubic centimetre of any body at that temperature, expressed in grammes, is therefore identical with its specific gravity.

For determining the specific gravities of bodies various methods are employed, differing according to whether the body under consideration is a solid, a liquid, or a gas; whether it is heavier or lighter than water, or insoluble or soluble in it.

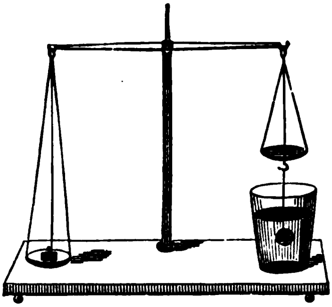
**16. Solids heavier than Water.**—Fill a vessel with water (Fig. 3), and drop in it a piece of sulphur which has been weighed. A quantity of water will then escape into the dish below, equal in bulk to the sulphur. Weigh the escaped water in the lesser vessel. If the sulphur weighed two ounces, the water will weigh an ounce. That is, the sulphur weighs twice as much as an equal volume of water; its specific gravity is therefore two. The best plan, however, is to suspend the solid to the scale-pan of a balance by a fine thread or hair, and then counterpoise it, or get its weight in the air. Immerse the suspended body in a vessel of distilled water (Fig. 4), and, as it weighs less, remove weights enough from the opposite scale-pan to restore the lost equipoise. Now divide the original weight in air by the loss in water, and the quotient is the specific gravity of the substance. For instance, a piece of lead weighs in air 820 grains, and loses in water 71 grains. The weight in air divided by the loss in water gives 11.5 as the specific gravity of the lead.

FIG. 3.



The Solid displaces its Bulk of Water.

FIG. 4.



Weighing a Substance in Water.

**17. Solids lighter than Water.**—When the body to be examined is lighter than water, it is first weighed and afterward attached to a piece of metal heavy enough to sink it, and suspended from the balance. The weight of a bulk of water equal to that of the piece of metal and light body together is thus found, and, the operation being afterward repeated with the piece of metal alone, the difference between the weights of the two bulks of water displaced gives the weight of water displaced by the light body.

**18. Powdered Solids.**—The specific gravity of any substance in powder—as, for instance, a soil—is obtained as follows: Counterpoise a thousand-grain bottle and weigh into it 150 grs. of soil to be tested. Fill with water and weigh again; water and soil give, say 1,096 grs., 150 of them are soil, and 946 water; consequently 54 grs. of water have been displaced by 150 grs. of soil. The calculation is then easy, 54 : 1.000 : : 150 : 2.777 sp. gr. of the soil. In practice a precaution is to be observed. The soil contains air among its particles, which would vitiate the result. To obviate this, fill the bottle but half full of water at first, and shake it well with the soil; the air escapes, and the bottle may then be filled with water.

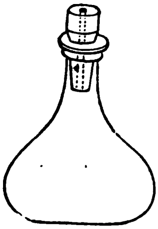
**19. Soluble Solids.**—When the substance to be examined is dissolved by water, its specific gravity is determined by substituting for the water some other liquid that does not dissolve it, and the specific gravity of which has been accurately established. The bulk of water corresponding to the bulk of the substituted liquid displaced may be found by simple proportion. The liquids most generally used in these determinations are alcohol and oil of turpentine.

**20. Liquids and Gases.**—To determine the specific gravity of liquids, procure a small bottle, and make a fine mark with a file and ink upon its neck. Counterpoise it in the balance. Fill to the mark with distilled water at 60° Fahr., and weigh it. Empty and fill again with the liquid, the specific gravity of which is required. Its weight, divided by that of the water, gives the desired result. Suppose the bottle holds a thousand grains of pure water, it will be found to hold 1,845 grains of sulphuric acid, which therefore has a sp. gr. of 1.845. For 1000 : 1.000 : : 1845 : 1.845. It will hold 13,500 grs. of mercury, the sp. gr. of which is hence 13.5; or 1,030 grs. of milk, sp. gr. 1.03. In practice it is usual to employ a bottle (Fig. 5), holding exactly 100 or

1,000 grains of distilled water at 60°, which shows the result at once without calculation.

The specific gravity of gases is obtained in a similar manner. A flask or globe suspended from the arm of a balance is weighed when empty, and again when filled with air. This gives the weight of air, which is taken as unity. Other gases are then substituted for the air, and their comparative weights ascertained. Gases are subject to variations of density, not only by alterations of temperature, but by changes of atmospheric pressure; these weights are therefore taken at the standard barometric pressure of 30 inches.

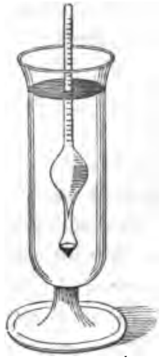
FIG. 5



Sp. Gr. Bottle.

**21. Hydrometer.**—Take a tumbler, or a light, slender-necked bottle, loaded with some shot, and float it in pure rain-water; it will sink to a certain depth, which may be accurately marked upon the glass. If now placed in brine or milk, the mark will stand above the surface; the vessel not sinking so deeply as before, because the liquids are heavier. Place it in alcohol, and the mark will disappear below the surface; it sinks deeper than at first, because the liquid is lighter than water. Instruments arranged on this principle, and called *hydrometers*, are used to measure the specific gravity of fluids. They usually consist of a glass stem (Fig. 6), terminating in a bulb below, loaded with shot or mercury, and floating in a narrow glass vessel, containing the liquid to be tested. Scales are fixed within the stem, zero being the point at which the instrument sinks in distilled water at 60° Fahr. In lighter liquids it sinks deeper, and the scale ascends from zero. In heavier liquids it

FIG. 6.



Hydrometer.

floats higher, and the scale is reversed. These scales are arbitrary and different in the various instruments. Tables accompany them, so that we see at a glance the sp. gr. which corresponds to any number upon the scale. Instruments of this kind are much used by manufacturers and dealers to determine the specific gravity or strength of liquors, syrups, oils, lyes, etc.

**22. Importance of Specific Gravity.**—Specific gravity is among the most important of the physical properties of bodies. It affords an important means of identifying them. The mineral, iron pyrites, for example, is in color almost exactly like gold, and is frequently mistaken for it. But it is at once distinguished by the difference in specific gravity, an equal bulk of gold being nearly four times heavier than pyrites. So, if gold is debased by alloying it with a cheaper metal, taking the specific gravity promptly detects the fraud. The proportion of alcohol in spirituous mixtures, the richness of milk, the strength of various solutions employed in the arts, and the identity and purity of many substances, are determined with more or less accuracy by finding this property.

**23. Density.**—Specific gravity is often confounded with density, but there is an important difference. The specific gravity of a body is the ratio of its weight to that of an equal volume of some substance selected as the standard, and it implies no unit of volume in the determination. The density of a body, on the other hand, is the amount of matter by weight that it contains in a fixed unit of volume compared with some substance taken as a standard. In the English system it is the weight in grains of a cubic inch, and may be expressed as a ratio by comparing it to the weight of a cubic inch of water. In the French system density is the weight in grammes of a cubic centimetre.

# CHAPTER II.

## MOLECULAR ATTRACTIONS.

### § 1. *Minute Constitution of Matter.*

**24. Its Interior Structure.**—From the force which acts between masses at all distances, we now pass to the study of a class of forces which only come into play when bodies are in contact. They seem to pertain to the interior structure of substances, and hence, before treating of them, it becomes important to refer to that interior structure, or how matter is believed to be constituted.

**25. Porosity of Matter.**—If we place a little water upon chalk or cloth, it disappears; in a certain sense it penetrates them, but it only passes into vacant places termed *pores.* Not only loosely-composed substances, as soil and flesh, but wood, rocks, stones, and even dense metals, have the same porous texture. Liquid mercury passes through lead, and water has been also forced through the pores of gold. Matter is, therefore, held to be universally porous.

**26. Motions of Internal Parts.**—If a closed India-rubber bag, filled with air, be squeezed, it will be compressed into less bulk—that is, the particles of air will be forced nearer together. If alcohol and water be commingled, the mixture occupies a smaller space than did the separate liquids; their particles have, therefore, approached closer to each other. If iron be hammered, it will be driven into less compass, the metallic particles being forced into closer relation. A certain amount of heat added to bodies in either the solid, liquid, or gaseous form, will cause a certain degree of expansion—that is, will cause the constituent particles to recede from each other; and, when the heat is withdrawn, the particles again approach.

**27.**—It is concluded from such facts as these that matter consists of exceedingly minute particles which are never in absolute contact, but are surrounded by unoccupied spaces, in which they are free to move under the action of forces. These ultimate separated material points, which are of great minuteness, are termed *molecules*, a word signifying a *small mass.* To the physicist molecules are not imaginary, but actual things with weights and magnitudes, and which do not change in the physical transformations of matter. Molecules play a prominent part in modern physical theory; and have made familiar the phrases molecular attractions, molecular forces, molecular constitution of matter. The chemical aspect of molecules will be considered in the chapter on Theoretical Chemistry, Part II.

**28. Divisibility of Matter.**—The division of matter may be carried to an amazing extent. Gold may be drawn out as a coating upon silver wire until the 492-thousand-millionth part of an ounce is still visible, with its proper metallic color and lustre. It has been estimated that, in a drop of the blood of the musk-deer, such as would remain suspended upon the point of a fine needle, there are one hundred and twenty millions of globules. But these examples of the divisibility of matter bring us only to the threshold of a world of wonders. Microscopic researches have introduced us to a realm of life peopled with animate beings, which are born, grow, reproduce their kind, and die; and yet so minute that many millions of them heaped together would not exceed in size a grain of sand.

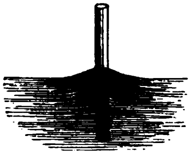
We will now notice some of those forms of force which are exerted between bodies only when in contact, and which are known as *molecular attractions.* They are manifested in the forms of matter, solid, liquid, and gaseous, which are known as *states of aggregation.*

## § 2. *Adhesion and Cohesion.*

**29. Their Differences.**—Though the molecules of a solid are separated, yet it does not crumble to pieces. They are held together by a force which reaches across their interstices and binds them in a fixed relation. When this force unites bodies dissimilar in kind, it is called adhesion. The sticking of chalk to a black-board, of mortar to bricks, of glue to wood, etc., are examples of adhesion. The same force, when acting between particles of the same kind, is termed cohesion. The form, solidity, hardness, elasticity, brittleness, malleability, and ductility of solids, are the result of various unknown modifications of cohesive force. There is also a mutual attraction among the particles of liquids. In a drop of liquid, cohesion attracts the particles into a rounded figure, against the influence of their weight, which would spread them out; pendant drops still further exemplify the same force.

**30. Adhesion of Liquids to Solids.**—If a glass rod be dipped in water, the liquid will rise round it above its level in the vessel (Fig. 7), and, when withdrawn, it will be *wet.* But, if the same rod be dipped in mercury, there is an apparent repulsion (Fig. 8), and the rod when withdrawn is *dry.* If a rod of gold be dipped in the mercury it is wetted, or covered with a mercurial film. The wetting in this case shows an attraction between the liquid and the solid, and that it is sufficiently strong to produce adhesion. But there may be attraction without wetting; glass is not wet by mercury, and still they are attracted, as may be thus shown. Suspend a flat, circular plate of glass to the arm of a balance,

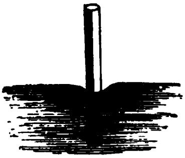
FIG. 7.



The Glass Rod in Water.

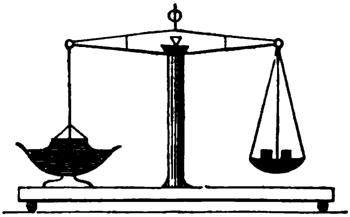
counterpoise it, and lower the plate (Fig. 9) over a cup of mercury. No matter how near the glass approaches, while there is no contact, there is no attraction. But, as soon as they are made to touch, a slight adhesion occurs, sufficient to lift a portion of the mercury above its level in the vessel, the amount of which may be exactly measured by the number of weights required to be placed in the opposite scale-pan to separate them.

FIG. 8.



Glass Rod in Mercury.

FIG. 9.

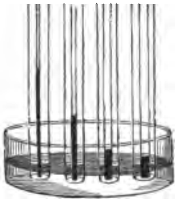


Attraction of Glass and Mercury.

**31. Conditions of Wetting.**—If the adhesive force of any solid for any liquid *exceeds half* the cohesive force of the liquid particles for each other, the solid will be wet. Thus, the adhesion of gold for mercury and of water for wood *exceeds half* the cohesive force of the mercurial and watery particles for each other, consequently water wets wood, and mercury wets gold. But, if the adhesion of the solid be *less than half* the cohesion of the liquid, wetting does not follow contact, as is exemplified by glass and mercury.

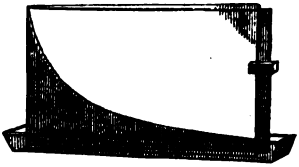
**32. Capillary Attraction.**—If glass rods with small apertures, open at both ends (Fig. 10), be dipped in water, the liquid immediately rises through the orifices to a height which increases in proportion to the smallness of the openings. The same thing may also be beautifully exhibited by placing two plates of glass (Fig. 11) upon their edges in a dish of colored water, one end being joined, and the other slightly separated. The influence of the gradually-approaching sides of the glass in attracting the liquid upward is seen in the course of the curve. From the circumstance that this effect is best produced by tubes with very fine apertures, the attraction that causes these phenomena is called *capillary* (from *capillus*, a hair).

FIG. 10.



Capillary Tubes.

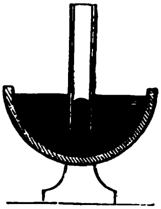
FIG. 11.



Rise of Liquid between Plates.

**33. Reversed Capillarity.**—If, now, a glass tube be dipped in mercury, we have again a disturbance of liquid equilibrium, but the effect is reversed. The interior column of mercury is depressed below the outside level, and its surface exhibits a convex shape, as seen in Fig. 12. The same thing occurs if the tube be greased and dipped in water, and in all cases where the liquid cannot wet the solid. The common belief, that depression in this case (as in that of the glass and mercury) is caused by repulsion, is quite erroneous. We have proved that, instead of repulsion, there is a strong attraction between glass and mercury. The reversed capillary action simply results from the preponderance of the cohesive over the adhesive force. In every body of fluid, each particle is kept in place by the mutual action of all the surrounding particles. But, if a column of fluid be separated from the surrounding mass by interposing the walls of a tube, *the sides of which exert no equivalent adhesive force*, the cohesion of the mass below draws down the upper and outer particles, and produces a roundness or convexity at the top.

FIG. 12.



Convex Liquid Surface.

**34. Adhesion of Gases to Liquids.**—When a liquid is poured from one vessel to another, the gases of the air adhere to the descending stream, are carried downward, and a portion of them remain combined with it. The force to be overcome by this adhesion is the elasticity of the gases, or the mutual repulsion of their particles. Pressure and cold lower the elastic force, and therefore favor absorption. As the temperature rises, adhesion is diminished, and hence the readiest means of driving out a gas from solution is by boiling.

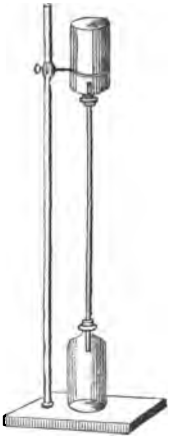
**35. Adhesion of Gases to Solids.**—If iron filings are gently dusted over the surface of water, they float, though iron is eight times heavier than water. This is because of the adhesion and condensation of a layer of air upon their surface, which prevents the water from wetting them. The condensed air around the particles forms a capillary cavity, and thus displaces a large volume of the liquid in comparison with that of the solid. Insects walk upon water and skim over its surface, because the air adhering to their feet forms capillary cavities, and prevents them from becoming wetted.

## § 3. *Diffusion.*

**36. Diffusion.**—Whenever the cohesive force subsisting between the molecules of any body is exceeded by the adhesive force subsisting between its molecules and those of another body, the cohesion of one or both bodies is overcome, their molecules separate, and become evenly intermixed. The bodies in this case are said to be dissolved in, or diffused through, one another, the process by which their particles become intermingled being termed diffusion. When diffusion takes place between bodies in unlike states of aggregation, one of the two, under the influence of adhesive attraction, assumes the state of the other. Thus, a solid or liquid, in order to become diffused through a gas, must first assume the gaseous state; gases and solids, to become diffused through liquids, the liquid state; and gases and liquids, to become diffused through solids, the solid state of aggregation. The term diffusion is generally limited to the molecular union or intermingling of bodies already in a like condition of aggregation.

**37. Diffusion of Gases.**—The molecules of gases exercise upon each other no cohesive attraction. Consequently, all gases when brought in contact will intermix, or diffuse through each other uniformly, and in all proportions, the process setting in even in opposition to their specific gravities. Thus, if two jars be connected by a narrow tube (Fig. 13), and the lower filled with carbon dioxide, the upper containing hydrogen, diffusion takes place through the narrow passage. The light hydrogen descends, and the carbon dioxide, though twenty times heavier, rises, and they become equally mingled in both jars. Our atmosphere owes its stability to this principle, its constituents being perfectly intermingled. The baneful products of respiration, combustion, and decay, instead of accumulating, are incessantly dissolved away and dispersed in the atmospheric ocean.

FIG. 13.

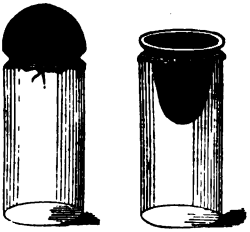


Diffusion of Gases.

**38. Rate of Diffusion of Gases.**—All gases do not, however, diffuse with equal facility. There is a very simple relation between the density of gases and the rapidity of their diffusion, which is expressed by saying that the diffusive power of gases varies inversely as the square root of their densities.

**39. Osmose of Gases.**—If a vessel be divided into two portions by a diaphragm or partition of dry plaster of Paris or some other porous substance, and each half filled with a different gas, diffusion will immediately commence. The rate of diffusion is governed by the law already mentioned, so long as the porous plate be very thin, but, when the plate is thick, the law observed is different. A distinction must also be carefully drawn between real diffusion through small apertures and the apparently similar passage of gases through membranous diaphragms, such as caoutchouc or bladder. In this mode of passage, which is called *osmose*, the rate of interchange depends partly on the relative diffusibilities of the gases, partly on the different degrees of adhesion exerted by the membrane, the gas which adheres most powerfully penetrating the diaphragm most easily. A sheet of India-rubber tied tightly over the mouth of a wide-mouthed jar containing hydrogen is soon pressed inward, even to bursting. If the jar be filled with air, and placed in an atmosphere of hydrogen, the swelling and bursting take place outward (Fig. 14). If the membrane is moist, the result is likewise affected by the different solubilities of the gases in the water or other liquid which wets it. Though the diffusive power of carbon dioxide is small compared with that of air, yet it easily passes into the latter through wet bladder. This process appears to be brought into play in atmospheric respiration. There is air on one side of the moist lung-membrane, and blood on the other; oxygen is transmitted from the air to the blood, and carbon dioxide from the blood to the air.

FIG. 14.



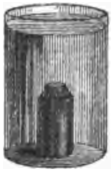
Passage of Gases through Membranes.

**40. Diffusion of Liquids and Solids through Gases.**—The diffusion of liquids through gases is a phenomenon of common observation. Water, as well as other liquids, at all temperatures, gives off vapors, which diffuse through the air as fast as they are formed. Solids in some cases do the same thing—ice, for example, evaporating very fast when in contact with a current of dry air. The law which governs these diffusions is indentical with that under which other gaseous bodies intermingle.

**41. Diffusion of Liquids.**—That the molecules of liquids cohere may be seen in the formation and persistence of drops. But, though thus held together by cohesive force, the amount of its action in liquids is never sufficient to unite large masses. The adhesive attraction of the molecules of dissimilar liquids, on the other hand, is in many cases very considerable. Diffusion of liquids through each other, though not universal as that of gases, may be observed in many cases. Thus, if a colored fluid, heavier than water—as, for example, ink—be placed in the bottom of a tall glass jar filled with water, taking care not to mix the two liquids by agitation, they will, after a time, be found commingled.

**42. Rate of Diffusion of Liquids.**—Different liquids under entirely like conditions diffuse with very unequal velocity. According to Graham, who placed small jars, filled with liquids to be tested, in larger ones containing distilled water, as in Fig. 15, and determined the amount of the inner solution that diffused into water in a given time, substances were found to differ greatly in diffusibility, chlorohydric acid proving to be the most diffusible. The equal diffusion of several solutions took place in the following times: Chlorohydric acid, 1; common salt, 2.33; sugar, 7; albumen, 49; caramel, 98. Substances thus tested are called *diffuseates.*

FIG. 15.

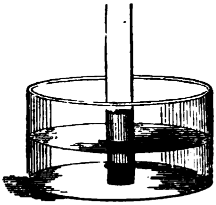


Diffusion of Liquids.

Diffusion is generally found to take place more rapidly at high than at low temperatures. It is particularly rapid with solutions of crystallized substances, like sugar, salt, etc., and slowest with those of non-crystalline bodies, which, like gelatine, gum, etc., are capable of forming jellies. The substances of great diffusibility have accordingly been designated as *crystalloids*, those of low diffusibility as *colloids.* Crystalloid bodies form solutions which are mobile, the solutions of colloids are viscid. When solutions of colloids are in contact, they hardly diffuse through each other, while the solutions of crystalloids not only diffuse with rapidity through the solutions of other crystalloids, but also through those of colloids.

**43. Osmose of Liquids.**—When a piece of moistened bladder is tied tightly over the end of a tube placed in a vessel of water, and then filled with alcohol up to the level of the outer liquid, the fluid in the tube will shortly begin to ascend, and may rise to a considerable height (Fig. 16). The external water passes through the membrane and mixes with the alcohol, while at the same time a feeble current of alcohol flows the other way and commingles with the water. When different liquids are separated by a membrane in this manner, the one is transmitted fastest which wets the barrier most perfectly. Dutrochet, who first drew attention to this matter, named the inflowing current *endosmose*, and the outflowing one *exosmose;* but these terms are lately less employed, and the phenomena are now known simply as *osmose*, from a Greek word signifying *impulsion.* The osmose of liquids is due partly to their adhesive attractions for each other, and partly to the difference of their adhesive attractions for the membrane or diaphragm, the pores of which act as short capillary tubes.

FIG. 13.



Osmose of Liquids.

**44. Diffusion of Gases through Liquids. Absorption.**—The diffusion of gases through liquids is called *absorption.* It is a phenomenon often noticed, the most common liquid, water, being possessed of high absorptive power. The power of absorption of liquids varies for different gases; pressure or cold increases it, heat diminishes it. The effect of pressure is often employed to induce absorption, as, for example, when water is impregnated with carbon dioxide to form the common beverage known as soda-water. When a mixture of different gases is brought in contact with a liquid, the absorptive power of the latter for each gas contained in the mixture will, however, be only proportional to the pressure of that gas, and not to that exercised by all the gases present.

**45. Diffusion of Solids through Liquids.**—The diffusion of solids through liquids, which is termed *solution*, is familiarly known. In this case the solid, assuming itself the fluid state, disappears, mixing uniformly with the liquid, which remains transparent. The solid is then said to have been *dissolved* by it, and the liquid employed is called the *solvent*. A liquid which dissolves one substance may refuse to dissolve another, while substances insoluble in one liquid are dissolved in others. A distinction must, however, be drawn between solution which depends entirely on diffusion and solution which is owing in part to chemical change. In the former case, as when sugar is dissolved in water, the sugar may be again obtained in an unaltered condition by the vaporization of the water, while in the latter instance, as when zinc is dissolved in sulphuric acid, the vaporization of the excess of the solvent will not yield the solid zinc, but an entirely different substance known as zinc sulphate.

**46. Conditions favorable to Solution.**—Whatever weakens cohesion favors solution. Thus, by powdering a substance, cohesion is partially destroyed and the surface increased; solution is consequently promoted. Heat, in most cases, contributes powerfully to solution, its effect being, as is supposed, to weaken cohesion by increasing the distance between the particles of the solid; yet there are marked exceptions. Water just above the freezing-point dissolves twice as much lime as at the boiling-point, while the solubility of common salt seems hardly affected by temperature. Some substances increase in solubility regularly as the temperature increases; in many cases the solubility increases faster than the temperature, and in others it rises with the increasing heat to a certain point, and then declines, while the temperature continues to ascend.

**47. Saturation.**—A liquid is said to be *saturated* when it has taken up as large a quantity of a solid as it can dissolve; in which case the force of cohesion between the particles of the solid is equaled by the adhesion of the solid and liquid to each other. The solvent power of liquids varies much. Water is the great solvent, and so general and important is its use that, in speaking simply of the solubility of a body, water is always understood.

**48. Separation of Solids from Solution.**—If the adhesive attraction between the solvent and the dissolved solid can be overcome, cohesive attraction resumes its sway, and reunites the molecules of the solid. This change may be effected in various ways—as, when the solvent is removed by evaporation, or, when another liquid, having no chemical effect upon the solid, is mixed with the solution. When a solution is evaporated, the solid is deposited either during the process, or remains at its close. The former is generally the case with crystalloid, the latter with colloid bodies. When the solid is separated by the addition of another liquid, the separation is due to the insolubility of the solid in the liquid added. Thus, if water be mixed with a solution of camphor in alcohol, the camphor separates as a white cloud, at first rendering the liquid turbid, but, after some time, depositing on the bottom of the vessel. The instantaneous separation of a solid from a clear liquid is termed precipitation, and, the deposit formed, a precipitate. As most frequently observed, however, precipitation is not due only to a reversal of solution, but also involves various forms of chemical action.

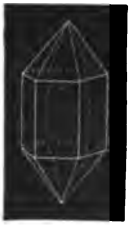
**49. Diffusion of Solids.**—The cohesive attraction subsisting between the molecules of any solid is much greater than the like attraction between the molecules of liquids. Their molecules being so much less mobile, diffusion cannot take place directly between solid substances; but, when they have been first diffused through liquids, and, the resulting solutions being mingled together, the mixed liquids are exposed to conditions under which the solids are compelled to again separate from the solvent, they will in some cases remain blended with, dissolved in, or diffused through, one another. This takes place, for example, when mixed solutions of magnesic sulphate and zinc sulphate in water are evaporated, and likewise with the mixed solutions of many other salts.

**50. Diffusion of Gases through Solids. Occlusion.**—The fact that gases adhere to solids has already been noticed. Under some conditions, certain solids absorb large quantities of gases, which appear to be truly diffused through the mass of the solid. Thus, the metals iron, platinum, and palladium, have the power of taking up various gases; the last-named metal is said to be capable of uniting in this way, at ordinary temperatures, with several hundred times its own bulk of hydrogen gas. Although not directly demonstrable by experiment, it is maintained that the hydrogen, having undergone intense condensation, must be in a state of solidity. This diffusion of gases through solids is termed "*occlusion*." No phenomena bearing the character of true diffusions of liquids through solids have so far been noticed.

## § 4. *Crystallization.*

51.—Under various conditions, and particularly when bodies pass from the liquid or gaseous state to the solid state, their molecules tend to arrange themselves in regular geometrical forms termed *crystals*, of which Fig. 17 may be taken as an example. The substances in which this tendency is marked are said to be *crystallizable*, and the process of their formation is called *crystallization.* Many substances, however, do not crystallize. They are, in that case, said to be *amorphous,* their molecular condition being distinguished as *amorphism.* Water, salt, sugar, are examples of crystallizable, gum and glass of amorphous bodies.

FIG. 17.



Crystal of Quartz.

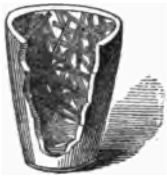
**52. Crystals in Nature.**—Nature teems with crystals. When it snows, the heavens shower them down, and ice is a mass of crystals, only so blended that we cannot distinguish them. Geology teaches that the materials of the globe were formerly in a melted state, so that in the slow process of solidification the opportunity was offered on the grandest scale for the formation of crystals. Hence vast rocky systems have their constituents crystallized, and are known as the crystalline rocks. Metallic ores are nearly all crystallized, and immense regions of granite are but mountains composed of crystals, varying in size from particles that can only be distinguished by the aid of the microscope up to masses sometimes weighing several hundred pounds.

**53. Artificial Crystals.**—Crystals may be artificially produced in various ways, as—from solutions, by the slow cooling of bodies in a state of fusion, by the condensation of gases, or even by rearrangement of the molecules of solids. When chemical action produces bodies not before present, they very frequently make their appearance in the form of crystals.

**54. Crystals by Solution.**—It has already been stated that the solvent power of liquids for any solid body is generally greater at high than at low temperatures. When, therefore, a hot, saturated solution of any such substance—as, for example, alum in water—is allowed to cool, a portion of the solid separates, and, in doing so, assumes the form of crystals. The liquid which remains after their formation has ceased is called the mother-lye, or *mother-liquor.*

**55. Crystals by Fusion.**—Nearly all bodies when cooled after melting take the crystalline form, though this may not be at first perceptible. The spaces left between the crystals which first form are completely filled up by the portions which solidify afterward, so that fracture reveals only a general crystalline structure, as may be observed in broken cast-iron and zinc. Common sheet-tin is beautifully crystallized, though it is not apparent. If with weak acid we wash off the thin surface-film of metal, which had cooled too rapidly to crystallize, the structure will be revealed of a beautiful feathered appearance. To obtain crystals by fusion, the excess of liquid must be removed from around those which are first formed. In this way beautiful sulphur-crystals are produced. If a quantity of this substance be melted, and then allowed to cool till a crust forms upon the surface and sides of the vessel, crystals will be formed within, which may be seen either by breaking the vessel (Fig. 18), or by piercing the crust and draining off the interior liquid.

Fig. 18.



Sulphur-Crystals.

**56. By Sublimation.**—Solid substances vaporized (*sublimed*) may be condensed in the crystalline form, as iodine, sulphur, arsenic. Camphor thus vaporizes and condenses in brilliant crystals upon the sides of apothecaries' jars by the rise and fall of common temperatures.

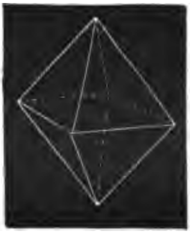
**57. Crystallization in the Solid State.**—The strong tendency of molecules to assume crystalline shape is manifested even in solids. Thus sugar-candy, at first transparent and amorphous, after some time becomes opaque and crystalline. Glass, by long-continued heat, though it does not melt, becomes also opaque and crystalline (*Réaumur's porcelain*). Brass and silver, when first cast, are tough and uncrystalline, but, when repeatedly heated and cooled, they become brittle, and show traces of crystallization. Even the little liberty the particles obtain by the motions of heating and cooling they improve to assume the crystalline condition. This is still better seen where the particles of bodies are thrown into motion by blows and vibration. Metals, by hammering, lose their ductility and tenacity, and become brittle and crystalline. Coppersmiths, when hammering their vessels, frequently *anneal* them, to prevent their flying to pieces; that is, they heat them, and then allow them to slowly cool. Thus also bells, long rung, change their tone; cannon, after frequent firing, lose their strength, and are rejected; and so the perpetual jar and vibration of railroad-axles and the shafts of machinery gradually change the tough, fibrous wrought-iron into the crystalline state, weakening them and increasing their liability to fracture.

**58. Crystals by Decomposition.**—It is also possible, by the decomposition or other chemical change wrought in various bodies, to obtain substances not before present in the shape of crystals. Thus, many compound gases, when passed through red-hot tubes, deposit crystals, and solutions of metallic salts are decomposed by the galvanic current, with the separation of the metals in the crystalline form.

**59. Phenomena attending Crystallization.**—This change of state is usually attended by change of bulk. Water in freezing expands to a considerable degree, and with great power; 1,000 parts of water are dilated to 1,063 parts of ice; and the force exerted by the particles in changing positions is so enormous as to burst the strongest iron vessels. Heat is always manifested when crystals are formed, in proportion to the rapidity of the change from the liquid to the solid state. Light has also occasionally been noticed to accompany the process, but its cause is not explained. Muddy and impure solutions often yield the largest crystals, and the presence of foreign bodies which do not themselves crystallize may thus modify the form which the crystal assumes. For example, common salt usually crystallizes in the form of a cube (Fig. 27), but, if urine be present in the solution, it takes the form of the octahedron. When a crystal is broken, there is a tendency to repair it; it continues to increase in every direction, but the growth is most active upon the fractured surface, so that the proper outline of the figure is restored in a few hours.

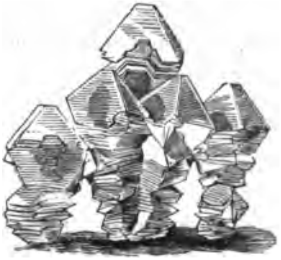
**60. Favorable and Unfavorable Conditions.**—Vibration may so disturb the process as to check the growth of those which have commenced, and start a second crop upon them. Crystals are seldom found perfect, being generally irregular, disguised, and distorted. Perfect alum-crystals, for example, are regular octahedrons (Fig. 19), but Fig. 20 shows how they appear in the large vat of the manufacturer. Sometimes the attractions are so balanced that a jar or agitation is needed to start the action. In a perfectly still atmosphere, water may be cooled eight or ten degrees below the freezing-point without congealing, but the vibration of the vessel produces a sudden crystallization of part of the liquid into ice. Any solid body intruded into the liquid, by adhesion, may destroy the equilibrium and begin the play of the crystallizing attractions. Thus, threads are stretched across vessels containing solutions of sugar, and form a nucleus around which rock-candy is crystallized.

FIG. 19.



Crystal of Alum.

FIG. 20.



Masses of Imperfect Alum-Crystals.

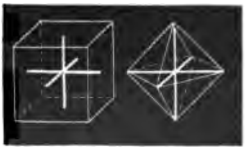
**61. Forms of Crystals.**—Leaving disturbing influences out of view, all liquids tend to assume the spherical shape of drops. We might, therefore, anticipate that, in returning to the solid state, their molecules would still group themselves round centres into spheres. But, although something of this kind may take place with amorphous bodies, the forms produced in the solidification of crystallizable substances are angular, and bounded on all sides by plane surfaces symmetrically arranged.

**62. Elements of Crystalline Form.**—Although there is an almost endless diversity in the forms which substances take when crystallizing, crystals are built up in obedience to universal geometrical laws, and present in the most varied forms certain constant elements of construction. All crystals are solids of the class known to geometry as *polyhedrons;* they are bounded by plane surfaces, or *faces*, which meet by twos in stright lines, or *edges*, inclosing between them *interfacial angles.* The faces, *polygons* in shape, present three or more *plane angles*, and three or more of these, having a common apex, inclose a *solid angle.*

**63. Axes of Crystals.**—Single crystals often present a large number of faces, but the position of all of these bears a fixed mathematical relation to that of the faces of simpler forms, so that the former may be calculated when the latter are known. These simple shapes, from which the others are said to be *derived by modification*, are termed *primary forms.* The primary forms, as usually assumed, are solids bounded by six quadrilateral faces meeting in twelve edges and eight solid angles. Every one of the faces will be opposite and parallel to another; therefore, when their centres are connected by straight lines, these must be three in number, and intersect each other in the centre of the primary. In some cases it has been found more convenient to assume four. They are termed the *axes* of the crystal, and it is known that all the faces observed in any crystal, when extended to meet them, will always do so at distances from the centre, bearing a very simple numerical relation to the distances at which they are met by the faces of the primary form. The different geometrical elements of crystalline form are thus mutually dependent; hence, when a certain number of these are known, the rest may be computed. Accordingly, when it is desired to determine the position of all the faces, the length of the axes, etc., of any crystal, all that is required is the measurement of some of the interfacial angles, an operation performed by the aid of certain instruments called *goniometers.*

**64. Systems of Crystallization.**—All the different crystalline forms which have been observed have been classified and arranged in a number of groups termed *systems of crystallization.* There are six of these systems, and the forms belonging to each of these differ from the forms belonging to the other systems, either in the number or the relative length of the axes, or in regard to the angles which the axes form at their intersection in the centre of the crystal.

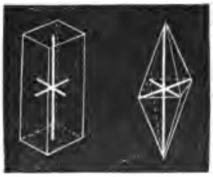
FIG. 21.



Regular System.

**65. Monometric or Regular System.**—In the forms of this system (Fig. 21) the axes are three in number, of equal length, and intersect each other at right angles. Crystals of this system expand equally in all directions by heat, and refract light in the ordinary manner. Common salt and iron pyrites are examples.

FIG. 22.

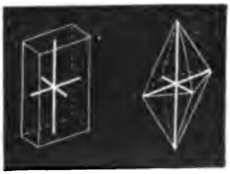


Square Prismatic System.

**66. Dimetric, Quadratic, or Square Prismatic System.** — In this system there are three axes intersecting each other at right angles. Two are equal, the third is of a different length. Its forms expand by heat equally in *two* directions only, and split the ray of light passing through them (*double refraction*), as do also the forms of the four systems remaining to be noticed. Examples: stannous oxide and mercuric cyanide.

**67 Trimetric, Rhombic, or Right Prismatic System.**—In the forms of this system, the three axes are also at right angles to each other, but all three of unequal length. Crystals of this system (Fig. 23) expand unequally in the three directions of the axes. Nitre and topaz may be taken as examples.

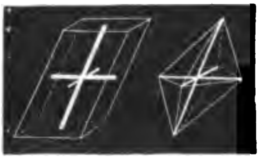
FIG. 23.



Right Prismatic System.

**68. Oblique Rhombic or Oblique Prismatic System.**—The forms of this system have three axes, which may be unequal (Fig. 24). Two are placed at right angles to each other, and the third is oblique to one and perpendicular to the other. Sodic sulphate and borax are common examples.

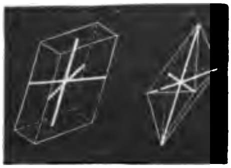
FIG. 24.



Oblique Prismatic System.

**69. Oblique Rhomboidal or Doubly Oblique Prismatic System.**—In this there are three axes, which may be all unequal and all oblique (Fig. 25). Examples: cupric sulphate and bismuthous nitrate.

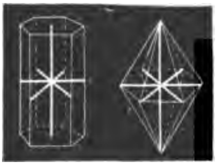
FIG. 25.



Doubly Oblique Prismatic System.

**70. Rhombohedral or Hexagonal System.**—The forms of this system (Fig. 26) differ from those of the others in having four axes, three of which are equal, in the same plane, and inclined at angles of 60°, while the fourth is of different length and perpendicular to the other three. Examples: quartz, Iceland spar, and ice.

FIG. 26.



Rhombohedral System.

**71. Axial Polarity.**—The axes of crystals are not mere imaginary lines. The force which builds the crystal works unequally, and endows it with different powers in different directions. In those crystals where the axes are all equal, light, heat, and electricity, are conducted equally in every direction. But, where the axes are unequal, conduction of heat and electricity, hardness, elasticity, transparency, expansion by heat, and luminous refraction, are correspondingly unequal, showing an actual difference of structure in the different directions, just as wood varies in qualities when tested with or across the grain. This perfect regularity of structure in crystals, by which they manifest different powers in different directions, can only be explained by supposing that attraction, in causing molecules to cohere in crystalline combination, does not act equally all around each molecule, but between certain sides or parts of one and corresponding parts of another; so that, when allowed to unite according to their natural tendencies, they always assume a certain definite arrangement. This property of molecules is called *polarity*, because in these circumstances they seem to resemble *magnets*, which attract each other by their poles.

**72. Cleavage.**—If we apply the edge of a knife to a piece of mica, it may be cleft into thinner plates, and these may again be separated into the thinnest films. Nearly all crystals will thus separate in certain directions, disclosing polished surfaces, and showing the order of formation of successive parts. This mechanical splitting of crystals is termed *cleavage*. Amorphous solids do not cleave, but fracture irregularly and in any direction.

**73. Derivation of Form.**—The cube (Fig. 27) may be taken to illustrate change of figure, and this is chiefly effected by replacing edges and angles by planes. The cube has twelve edges and eight solid angles. If plane-surfaces are substituted for the edges, we get the secondary form (Fig. 28). If we replace the solid angles by planes, we have the form Fig. 29. If both these replacements occur together, the more complex (Fig. 30) results. If the edges of the cube be replaced until all traces of the original planes disappear (Fig. 31), the rhombic dodecahedron is formed. And, if the solid angles be replaced by planes to the same extent, we get (Fig. 32) the regular octahedron.

FIG. 27 FIG. 28. FIG. 29

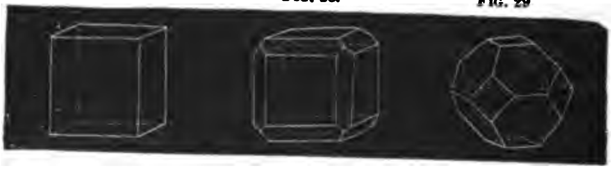
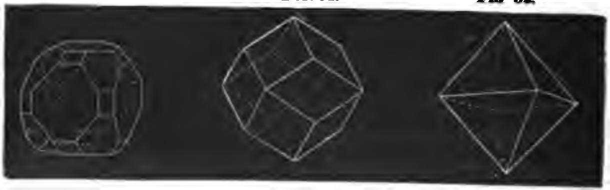


FIG. 30. FIG. 31. FIG. 32.



Transformations of the Cube.

We have said that the secondary or derived forms of crystals are almost innumerable. Six hundred modifications of the six-sided prism have been enumerated by Dr. Scoresby among snow-flakes, while M. Bournon, in a two-volume treatise, has delineated eight hundred different forms of the mineral calcite (calcic carbonate). Hauy has described a single crystal which had one hundred and thirty-four faces.

**74. Isomorphism.**—When different substances take upon them the same primary form or modifications of it, they are said to be *isomorphous*, and the law which governs their identification is called *isomorphism*, from the Greek *isos*, equal, and *morphe*, form. Thus gold, silver, copper, alum, salt, and many other bodies, all crystallize in forms of the monometric system, which perfectly resemble each other. Such perfect identity is, however, only met with in forms of this system; in all others, the lengths of the axes, or their inclinations, or both, varying slightly, produce always small differences in the geometrical elements of their forms. For this reason the term *homœomorphous*, signifying similarly formed, has sometimes been employed in place of the one above mentioned. Isomorphous bodies, when crystallizing from mixed solutions, frequently remain diffused through one another in the solid state. Some substances crystallize in two different forms, and are called *dimorphous*. Thus, sulphur deposited from solution takes one form, and when cooled from melting, another. Nitre crystallizes in one shape in large quantities, and takes another shape in small quantities. Substances crystallizing in three forms are called *trimorphous*.

**75. Molecular Motions.**—The changes considered in this chapter are resolvable into molecular movements. It is held that the molecules are always in motion, and by virtue of their motions are centres of molecular energy. The molecular units are supposed to have three kinds of motion. In solids they maintain their relative places, but vibrate at such varying rates as to emit all the colors of the spectrum. In liquids the molecules are loosened from their structural relations, and circulate among each other so rapidly as to give rise to energetic liquid diffusion. When the violence of these motions is increased by heat, the molecules are shot beyond cohesive restraint, and assume the condition of gas. No longer influenced by mutual attractions, they are now supposed to move with far greater energy, flying about in all directions, in extremely short, straight paths, striking and repelling each other, and giving rise to an expansive pressure, known as gaseous tension. This is the molecular explanation of the phenomena presented by the three states of matter.

# CHAPTER III.

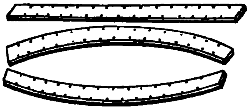
## HEAT.

### § 1. *Thermal Expansion.—Thermometers.*

**76.** HEAT exerts a very powerful influence over the states of matter, and is so important for the production of chemical effects, that the chemist has been called the "Philosopher by Fire." The general science of heat is termed *Thermotics*, from the Greek *thermos*, hot, which gives us also the words *thermal*, *thermometer*, etc.

**77. Expansion of Solids.**—Heat is a force of repulsion, and its general effect upon matter is to separate its particles, or to expand it. All bodies of uniform constitution expand equally in all directions, when heated, while other substances, as crystals and wood, in which the particles are differently arranged in different directions, expand unequally. With a given amount of heat, the same substance always expands to the same degree; but the same quantity of heat causes different substances to expand unequally. This may be shown by riveting together thin slips of different metals, for instance zinc and iron, into a straight bar, Fig. 33. When dipped into hot water it is warmed, and the zinc, expanding most, becomes longest; the bar curves, the zinc forming the convex side. If placed in ice-water, the zinc contracts most, and the bar curves in the opposite direction. Heat thus antagonizes cohesion: and

FIG. 33.



Expansion of Compound Bars.

a quantity of heat, applied at a high temperature, produces more expansion than the same amount at a low one.

**78. Expansion of Liquids.**—If sufficient heat be imparted to a solid, it overcomes cohesion, and liquefies it. Liquids, thus produced by heat, are also expanded by it, and to a much greater degree than solids. While iron increases from freezing to boiling but $\frac{1}{812}$ of its volume, water expands $\frac{1}{23}$, and alcohol $\frac{1}{9}$.

**79. Expansion of Gases.**—But liquids cannot be indefinitely expanded; a sufficient repulsion of their atoms changes them into gases. As a general law gases expand much more than liquids, although certain liquids, as sulphur dioxide, are among the most expansible bodies known. As there are no varying cohesions to overcome, gases expand very nearly alike, increasing from the freezing to the boiling of water more than one-third of their bulk.

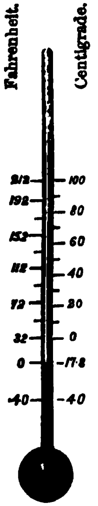
**80. Measurement of Heat.**—As the effect of heat is expansion, the measurement of expansion becomes the measurement of the force. The common instruments for measuring heat are called *thermometers.* They measure not quantity of heat, but *temperature.* Heat is the force producing the effect; and temperature the intensity with which it acts. Liquids are better adapted as heat-measurers than either solids or gases; as in solids the expansion is too slight to be easily perceptible, and gases are too sensitive to changes of atmospheric pressure to fit them for this purpose.

**81. Mercurial Thermometer.**—To make this instrument, a fine glass tube, with a bulb upon the end, is partly filled with mercury. The air is expelled from the rest of the tube by heating it till the mercury rises by expansion to the top, and at that moment the glass is hermetically sealed by melting the end of it with a blow-pipe. As it cools, the mercury falls in the tube, leaving a vacuum above.

Mercury has several important advantages as a thermometric fluid. It is readily obtained pure, and does not adhere to the tube; it is sensitive to heat, expands with greater regularity than most liquids, and has a range of 700° between freezing and boiling. Temperatures below the freezing point of mercury are usually determined by thermometers filled with alcohol, tinged with some coloring matter, to make it visible. As mercury boils at 660°, temperatures above that point are measured by the expansion of the air, or by the aid of thermo-electric currents, the metals iron and platinum being sometimes selected for the combination.

**82. Thermometric Scales.**—The sealed tube is attached to a brass plate engraved with the thermometric scale, Fig. 34, or, for chemical work, the divisions are engraved directly on the glass tube. It is then dipped into ice-water, and a mark made opposite the top of the column of mercury, called the *freezing-point.* It is now introduced into boiling water, and the height to which the column rises is marked as the *boiling-point.* These are natural standard points which serve as a basis for the division of the scale. In the *Centigrade* thermometer of *Celsius*, the freezing-point is called zero, and the interval between that and the boiling-point is marked off into 100 equal spaces called degrees. In Réaumur's scale the same space is divided into 80 degrees.

FIG. 34.



Thermometric Scale.

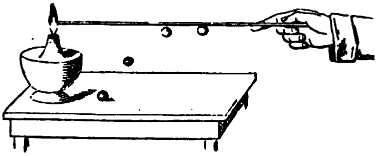
(*See* Appendix.)

The scale named after its inventor, Fahrenheit, and which has, unfortunately, come into general use in England and this country, is not so simple. He divided the space between freezing and boiling into 180 degrees; but, instead of starting at the freezing-point, he thought he would find the lowest possible cold, and make *that* zero. So with snow and ice he got the mercury down to 32° below the freezing-point, and commenced counting there. On this scale, therefore, freezing occurs at 32°, and boiling at 212°. The several scales are distinguished by their initial letters F., C., and R. The Centigrade, affording decimal subdivisions, is the most simple and rational, and is gradually coming into use for scientific purposes. In all of these scales, degrees below zero are distinguished from those above by prefixing the minus-sign (—).

## § 2. *Transference of Heat.*

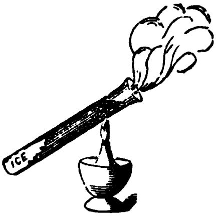
**83. Conduction of Heat.**—Heat moves, or is transferred, in several ways, known as *conduction*, *convection*, and *radiation*. If several marbles are stuck by wax to a copper rod, Fig. 35, and heat be applied to one end, it gradually passes along the rod, the wax is melted, and the marbles drop off successively. The heat, in this case, is said to be *conducted.* Generally, the more dense a body is, the better it conducts; solids are better conductors than liquids, and liquids than gases. As a class, metals are the best conductors, but they differ much among themselves in this respect. The imperfect conduction of liquids may be shown by filling a glass tube with water, inclining it over a lamp, and applying the flame at the upper end, Fig. 36. The water will boil at the surface, while at the bottom there may still be ice for a considerable time. Dry air is one of the poorest conductors. Loose materials, as wool, cotton,

FIG. 35.



Conduction of Heat.

FIG. 36.

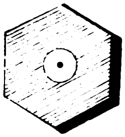


Non-conduction of Liquids.

sawdust, are bad conductors, chiefly owing to the air inclosed in their spaces.

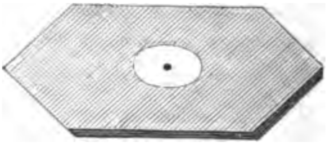
**84. Influence of Internal Arrangement.**—A slice of quartz cut *across* its axis, Fig. 37, was perforated with a small hole and covered with a layer of white wax. A wire was then inserted through the orifice and heated by an electric current. The wax melted in an exact circle, which showed equal conduction in all directions. A slice cut *parallel* with the axis, as in Fig. 38, treated in the same way, gave an oblong outline of the melted wax, showing that heat travels with more facility *along* the crystalline axis than across it. The metal bismuth conducts both heat and electricity better along the planes of cleavage than across them. The same thing has been found in reference to wood; it transmits heat better along the course of the fibres than across them.

Fig. 37.



Equal Conduction.

Fig. 38.



Unequal Conduction.

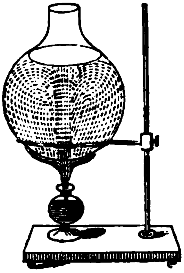
**85. Conduction influences Sensation.**—The carpet feels warmer to the naked feet than oil-cloth, because the latter conducts away the heat faster from the skin, although both are at the same temperature. If the hand be placed upon silver at 120°, it will be burned, owing to the rapidity with which heat leaves the metal and enters the flesh. Water will not scald the hand if it be held quietly in it till it reaches 150°, while the contact of air at 250° or 300° may be endured.

**86. Convection.**—Although liquids and gases are poor conductors, yet, from the mobility of their particles, they may be rapidly heated by a process of circulation or *con-*

*vection.* If heat be applied to the bottom of a vessel containing water, the lower portion of the liquid is warmed, expands, becomes lighter, and ascends, its place being taken by the colder liquid at the sides—thus forming a set of currents which diffuse the heat through the whole mass.

Gases are heated in the same manner. The warm air in contact with a stove or other heated body becomes lighter, and ascends, while the colder and heavier air rushes in to supply its place. This, becoming heated, also ascends, and thus a system of currents is established, which diffuses warmth through the apartment.

Fig. 89.



Circulation of Heat.

**87. Radiation of Heat.**—While standing at some distance from a hot stove we are warmed by it. It emits a constant stream of heat-rays in straight lines, at a very high velocity, and which have the power of raising the temperature of any body that receives them. Heat moving in this way is called *radiant* heat, and the act of transference *radiation.* All bodies radiate heat at all times, the rate of emission depending upon the temperature. If a cannon-ball, at 1,000°, be placed near another at 100°, they radiate heat to each other, but that at 1,000° loses it faster than it receives it, and its temperature falls; while that at 100° receives heat faster than it parts with it, and its temperature rises. After a time they both come to the same temperature, the radiations are equal, and an equilibrium is established. All bodies are thus exchanging heat with each other, and tending to an equilibrium of temperature.

**88. Influence of Surface.**—Radiation is influenced by surface. A cubical vessel of tin had one of its sides coated with a layer of gold, a second with silver, a third with copper, and a fourth with varnish. The vessel was then filled with hot water, and placed at a little distance from the thermometer. When the hot gold surface is turned to it, scarcely a trace of effect is observed, and so with the copper and silver; but, when the varnished surface is brought round, a stream of heat strikes the bulb, and the mercury quickly rises. The physical condition of the surface also influences radiation—rough, uneven surfaces being more active than bright polished ones; hence, if the metal is covered with woolen or velvet, its radiant power is increased. Bright metallic vessels, therefore, retain the heat much longer than those which are tarnished.

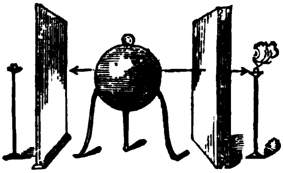
**89. Absorption.**—Good radiators are good absorbers of heat; that is, the surfaces which can easily give out heat will easily take it in. On the contrary, a bad radiator, as a bright metallic surface, is a bad absorber, and therefore a good reflector. Hence, the thinnest metallic film upon a surface powerfully protects it from the action of radiant heat.

**90. Dew.**—When the radiation of bodies is not compensated, their temperature sinks. Such is the case with objects exposed to the sky on clear nights. If good radiators, they rapidly lose heat, and, cooling below the temperature of the air, at length begin to condense its moisture upon their surfaces: this is *dew*. The best radiators, as grass, leaves of trees, and porous soils, receive the most dew, while poor radiators, as smooth stones, and hard, compact soils, remain almost dry. Clouds radiate back the heat received from the earth, so that cloudy nights are warm and dewless. If the temperature sinks lower than 32°, the moisture is frozen, and becomes frost.

**91. Two Kinds of Radiant Heat.**—It is well known that radiant heat is constantly associated with light, and the laws of its movement are the same as those of light. That which accompanies light is called *luminous* heat; but that which is emitted from dark bodies, as from a stove below redness, or from the hand, is called *obscure*, or *dark* heat. But dark radiant heat obeys the same laws of motion as light and luminous heat.

**92. Diathermancy.**—Bodies which transmit heat freely are called *diathermic;* those which arrest it, *athermic.* Rock-salt (common salt in blocks) is the most perfect diathermic body, allowing all the heat-rays—those from the sun and the hand—to pass through with equal freedom. What glass is to light, a plate of rock-salt is to heat, and it has hence been aptly termed "the glass of heat." This substance is therefore adapted to make prisms and lenses for the concentration and dispersion of dark heat. If a heated ball be placed between a plate of glass and one of rock-salt, Fig. 40, and bits of phosphorus be laid upon stands beyond, though the salt be many times thicker than the glass, the dark heat passes freely through it, igniting the phosphorus, while it is quite arrested by the glass.

FIG. 40.



Glass intercepting, and Rock-Salt transmitting Heat.

**93. Absorption of Heat by Aqueous Vapor.**—Aqueous vapor, when condensed to minute particles of water, is highly opaque to the dark radiations. Where the atmospheric gases arrest one ray of obscure heat, the small proportion of water suspended in the air stops sixty or seventy rays. Luminous solar heat penetrates the air, and, falling upon the earth, is changed into obscure heat, which cannot be radiated back into space. The watery particles are thus the "barb" of the atmosphere which prevents the escape of the heat, and thus maintains the temperature of the earth. It follows that, if aqueous vapor were withdrawn from the air, the terrestrial heat would so quickly radiate away that the earth would soon become uninhabitable; the invisible watery element of the air is, therefore, the blanket which keeps the world warm. In all those localities where the atmosphere is *dry*, the nightly loss of radiant heat is great, so that even in the burning desert of Sahara there is nocturnal freezing.

## § 3. *Changes of Molecular Aggregation.*

**94. Liquefaction.**—Heat applied to solids overcomes their cohesion and changes them to liquids. That degree of temperature which is required to liquefy a substance is called its *melting-point.* From hundreds of degrees below zero up to thousands above, the various substances of Nature melt at different temperatures, showing that each requires its particular amount of heat-force to throw it into the liquid state.

**95. Latent Heat.**—In effecting this change, a certain amount of heat disappears, or seems to be used up in the process; and, as it can no longer be detected as *sensible* heat, it is spoken of as *latent* heat. If we take an ounce of ice at 32°, and one of water at 174°, and put them together, when the ice is melted, we shall have two ounces of water at 32°. The ounce of hot water has, therefore, lost 142° of its heat in melting the ice, which amount is the "latent heat" of the resulting water. The amount of heat thus consumed in altering the form of bodies, without raising their temperatures, is different in different cases.

**96. Specific Heat.**—If we expose equal weights of different substances to the same source of heat, they do not all receive it with equal readiness or in equal amounts; some will receive more than others. Water requires thirty times as much heat as mercury to raise an equal weight of it through the same number of degrees. Hence bodies are said to have different *capacities* for heat, and, as each substance seems to require a particular quantity for itself, that quantity is called its *specific* heat. The art of measuring the specific heat of bodies is called *calorimetry.*

**97. Heat liberated by Freezing.**—If the change of a solid to a liquid *consumes* force, the reverse change must *produce it;* the force therefore reappears as heat, upon freezing. As the thawing of snow and ice in spring is delayed by the large amount of heat that is expended in the forming of water, so the freezing processes of autumn are delayed, and the warm season prolonged, by the large quantities of heat that escape into the air, from the changing of water into ice.

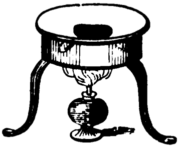
**98. Freezing Mixtures.**—Advantage is taken of the absorption of heat in liquefaction to produce freezing mixtures, the most common example of which is salt and ice. In this case the salt melts the ice to unite with its water, which in turn dissolves the salt, so that both solids are changed to liquids. These changes require large amounts of heat, which is absorbed from surrounding bodies; the cold produced sinking the thermometer 40° below zero.

**99. Ebullition.**—When water is gradually heated, minute bubbles are formed at the bottom of the vessel, which rise a little way, are crushed in, and disappear. These consist of vapor or steam, which is formed in the hottest part of the vessel, but, as they rise through the colder water above, are cooled and condensed. As the heating continues, these rise higher and higher until they reach the surface and escape into the air, producing that agitation of the liquid which is called *boiling* or *ebullition.*

**100. Boiling-Point.**—The temperature at which this takes place is called the *boiling-point*, and it varies with different liquids and in different circumstances. It is slightly influenced by the nature of the containing vessel. To glass and polished metallic surfaces liquids adhere with greater force than to rough surfaces; and, before vaporization can occur, this adhesion must be overcome. Substances dissolved in a liquid also raise its boiling-point on account of their adhesion. Under ordinary circumstances, water boils at 212°, but, saturated with common salt, its boiling-point is 224°. It has lately been shown that the amount of air dissolved in the water affects its boiling-point, as it presses the watery particles asunder, and thus aids them to take on the gaseous state. Water purged of its air by long ebullition has been heated to 275° without boiling. When it did boil, the water was instantly changed into vapor with a loud explosion, the cohesion of its particles being suddenly overcome, like the snapping of a spring, by the repulsive power of the accumulated heat. But the most important circumstance that influences the boiling-point is the pressure of the atmosphere. This resists the rising vapor, and, as it fluctuates, the boiling-point varies. The pressure becomes lighter as we ascend into the atmosphere, and the temperature of the boiling-point is correspondingly diminished, so that boiling water is less hot in high altitudes than in low ones.

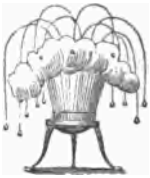
**101. The Spheroidal State.**—Water adheres to most surfaces, but heat destroys this attraction, and, if drops of it fall upon a red-hot plate of metal, they gather into spheroids, roll about, and evaporate very slowly. Fig. 41 represents a mass of water in the *spheroidal state*. In this case the heat of the metal produces a layer of vapor which supports the drop, so that it does not touch the surface, but is driven about by currents of heated air. The temperature of the spheroid never reaches the boiling-point of the liquid, as the vapor, being a non-conductor, does not transmit the heat from the metal, and, besides, it is kept

FIG. 41.



Spheroid of Water.

FIG. 42.



Its Explosion.

cool by evaporation from its surface. If the temperature of the plate be allowed to fall to a point at which the water wets its surface, it will be suddenly scattered in a kind of explosive ebullition, Fig. 42.

**102. Vaporization.**—The change of solids or liquids by the force of heat to vapor is called *vaporization.* Substances which are readily converted into vapor are said to be *volatile*, while those which are vaporized with difficulty are termed fixed or *non-volatile.* The slow formation of vapor from the surfaces of bodies is called *evaporation.* It goes on at all temperatures, even from the surface of ice and snow, but is rapidly increased as the temperature rises.

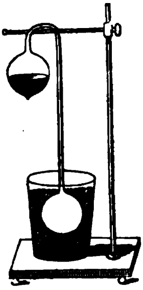
**103. Heat of Vaporization.**—A much larger amount of heat is spent in converting liquids into vapors than in changing solids to liquids, while the vapors are no hotter than the liquids from which they are formed. The heat has been consumed in producing the repulsive motion and the consequent enormous expansion of the gaseous body. If the liquid is exposed to the air, it is impossible to raise its temperature above its natural boiling-point. All the heat added after boiling commences is carried away by the vapor. Water boiling violently is not a particle hotter than that which boils moderately.

**104.**—The quantity of heat which disappears during evaporation is very large. With the same intensity it takes 5½ times as long to evaporate a pound of water as it does to raise it from freezing to boiling; it hence receives 5½ times as much heat. If, therefore, 180° were required to boil the pound of water, nearly 1,000° are necessary to change it to vapor, and, being spent in producing the change of state, it of course disappears as sensible heat. This quantity is, therefore, the "latent" heat of steam. If the process be reversed, and the vapor be made to reassume the liquid form, the heat reappears. The condensation of a pound of steam will raise 5½ pounds of water from the freezing to the boiling point.

**105. Cooling Effects of Evaporation.**—As evaporation consumes heat, it is a cooling process. We experience this in the cold sensation of evaporating a few drops of ether from the hand. As the perspiration evaporates from the skin, it becomes a powerful cooling agency and regulator of bodily temperature, while the vapor which escapes from the breath, by its absorption of heat, exerts a cooling effect within the body.

**106. The Cryophorus, or Frost-Bearer,** is an instrument which strikingly illustrates this principle. It consists of a tube with a glass bulb at each extremity, one of which contains a little water. Air is expelled from the instrument by boiling the water, the aperture through which the steam escapes being sealed, while the remaining space is filled with vapor. The empty bulb is then placed in a freezing mixture, Fig. 43, and the vapor condenses, its place being supplied by vapor from the water-bulb above. Condensation and evaporation go on so rapidly that the water is soon frozen.

FIG. 43.

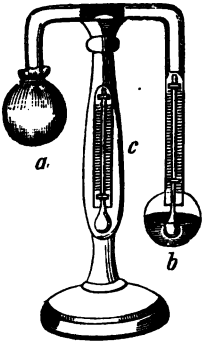


The Cryophorus.

**107. Dew-Point.**—The air always contains moisture, the amount of which varies with the temperature. The power of the air to absorb moisture is called its *capacity for absorption.* When it contains as much as it is capable of holding at a given temperature, it is said to be *saturated*, and any lowering of the temperature condenses it in the form of clouds, mist, fogs, dew, etc. The degree of temperature at which the moisture is condensed is called the *dew-point.* If the temperature of the air has to fall but a few degrees before moisture is deposited, the dew-point is said to be *high*, and there is much moisture in the air; while, if the temperature must fall far, the dew-point is low, and the air contains less moisture. It is obvious, therefore, that, by finding these two points of temperature, one can easily obtain the amount of atmospheric humidity.

**108. The Hygrometer.**—This is an instrument for measuring atmospheric moisture. Daniell's hygrometer, Fig. 44, is constructed on the principle of the cryophorus. The long limb ends in a glass bulb *b* half filled with ether, into which dips a small thermometer. The bulb *a* on the short limb is empty and covered with muslin. The temperature of the air is shown by another thermometer, *c*, affixed to the stand of the instrument. When an observation is to be made, a little ether is poured upon the muslin, and, as it evaporates, the temperature of the other bulb becomes reduced. When it is sufficiently cold to condense the moisture of the air, it will be covered with dew. The thermometer in the tube *b* shows at what temperature this deposition takes place, and, of course, gives the dew-point. The amount of moisture in the air of our artificially-heated rooms is a matter of great importance to health, and the hygrometer is very valuable in enabling us to determine it.

FIG. 44.

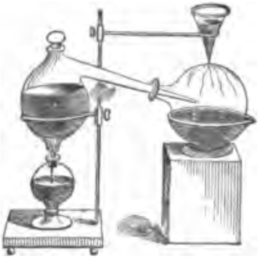


Daniell's Hygrometer.

**109. Volume and Density of Vapor.**—Equal bulks of different liquids generate unequal volumes of vapor. Water yields a larger amount than any other liquid. While a cubic inch of water gives 1,694 inches of vapor, a cubic inch of alcohol yields 528, one of ether 298, and of oil of turpentine 193. But, the less the volume of vapor, of course the greater its density. The density of vapor is increased, either by cold or pressure. The point at which its temperature cannot be further lowered, without returning to the liquid state, is called its *maximum density*.

**110. Elastic Force of Vapors.**—All vapors are elastic, and have a tendency to diffuse themselves through space, exerting more or less force against any obstacle that resists their expansion. This expansive force of vapors is called their *elastic force* or *tension*. The expansive force of heat, acting through the vapor of water, is the impelling power of the steam-engine.

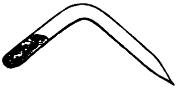
Fig. 45.



Distillation.

**111. Distillation** consists in vaporizing a liquid by heat in one vessel, and condensing it by cold in another, Fig. 45. The object may be either to separate a liquid from non-volatile substances dissolved in it, as in distilling water, to purify it from foreign ingredients, or to separate two liquids which evaporate at different temperatures, as alcohol and water. In the latter case, the heat is carried just high enough to vaporize the most volatile liquid. The product of the process is called the *distillate*. When solids are vaporized, the process is termed *sublimation*, and the condensed vapor a *sublimate*.

Fig. 46.



Condensation Tube.

**112. Condensation of Gases.**—When a gas loses heat enough to change it to the liquid or solid state, it is said to be *condensed*. Under the joint effect of pressure and extreme cold, many gases once considered permanent have been reduced to liquids, and some even to the solid condition. Dr. Faraday effected this by a very simple method. He placed the materials from which the gas was to be generated in one end of a glass tube bent in the middle, which was then hermetically sealed, Fig. 46. The expanding gas confined in so small a space exerted a tremendous pressure, the force of which condensed a portion of it into a liquid in the other end of the tube, which was immersed in a freezing mixture to facilitate the process. By this method, and at a temperature of –166°, he succeeded in liquefying carbonic dioxide, chlorine, ammonia, and several other gases, More recently M. Natterer, of Vienna, applied a cold of –220° F., and a pressure of 3,000 atmospheres; but some of the gases, as oxygen, hydrogen, nitrogen, refused to liquefy, even under this tremendous force.

**113. Heat and Chemical Action.**—Besides these physical changes and transformations, heat is also employed to effect innumerable chemical changes. By means of lamps, baths, and furnaces, the chemist is able to subject bodies to all degrees of temperature, and to promote and modify their action on each other. By its repellant action upon the constituent parts of matter, heat overcomes chemical attraction, destroys compounds, and brings new affinities into play with the production of new substances. At a sufficiently high temperature, indeed, we can conceive the repulsion to be so great that all affinities are suspended, and the chemical elements are dissociated.

## § 4. *The Nature of Heat.*

**114. Heat and Cold.**—The difference between heat and cold is merely one of degree, and we must be careful not to misinterpret their impressions upon ourselves. If we plunge one hand in ice-water and the other in hot water, and then transfer both to water intermediately warm, it will seem hot to the one and cold to the other. Indeed, if we trusted our ordinary sensations, we should believe in two opposite principles of heat and cold, a doctrine which was long advocated until it was found that these are merely relative, and that cold is but the absence of heat. Intense heat and intense cold produce the same sensations; frozen mercury blisters the flesh like hot iron. Putting aside, then, our sensations, what is it that we know concerning the nature of heat?

**115. The Caloric Hypothesis.**—In the foregoing brief statement of the actions and effects of heat, we have confined ourselves to facts which can be shown by experiment, and have spoken of heat merely as a force, or agent. But how are its effects produced? It has long been regarded as a kind of matter—a subtile fluid—an imponderable element, whose entrance into our bodies produces warmth, and its escape cold. This fluid *caloric* was supposed to be stored up in the interstices of bodies, some holding more than others, according to their various *capacities.* It was assumed to have an attraction for the particles of matter, and to combine with them, while its own particles are self-repulsive, and thus cause the atoms with which they unite to repel each other. This notion of the materiality of heat is now generally abandoned in the scientific world.

**116. Grounds of a New Theory.**—Facts were pointed out in the last century by Count Rumford which were wholly inconsistent with the caloric hypothesis, and many other facts of similar import have been since observed. If an iron bar is struck upon an anvil, its temperature is raised, and, if it continues to be hammered, it may be made red hot. Two sticks may be rubbed together till they take fire; and water may be agitated by friction till it boils. It is a general law, that arrested mechanical motion produces heat, and that the amount of heat produced depends not at all upon the capacities of bodies for heat, but upon the amount of mechanical force expended. Prof. Rood made the following beautiful experiment: A ball weighing a pound is allowed to fall from a height of one or two inches on a thermo-electric couple made by soldering together German-silver and iron. The heat thus developed generates a current of electricity which is measured by a galvanometer. The amount of heat generated was found to be directly proportional to the distance through which the ball fell. It has been demonstrated that 772 pounds falling through one foot of space produces sufficient heat to raise one pound of water 1° F.; and it has been further proved that one pound of water falling through one degree of temperature gives out sufficient heat to raise 772 pounds one foot high. This is known as the mechanical equivalent of heat, and was established by Dr. J. P. Joule, of Manchester, England, in 1850.

**117. Heat as a Mode of Motion.**—It is, therefore, now held that heat and mechanical force are *convertible into each other*, and this puts an end to the conceptions of heat as a material fluid; for, to be interchangeable, their forces must have a common nature. The convertibility is between molar motions and molecular motions—the motion of masses and the motion of particles. When a body is struck, the mechanical motion is arrested, but there is no destruction of force; it is only communicated to the particles of the body which are thrown into internal motion, and this is manifested as heat. Heat is, therefore, now defined as a "mode of motion" among the constituent parts of matter. We say that bodies are heated and cooled, and that one warms another near it. But we strictly mean only that they expand and contract, and that a body in expanding contracts others, and in contracting expands them. Hence, we find the effect of heat to be simply *a motion of expansion in matter* communicable from body to body. The motion of a mass implies the motion of its parts. If a body expands, it is because its parts have receded farther from each other, that is, have *moved.* Heat is therefore such a motion among the molecules of a body as gives rise to expansion.

The later views of the relations of force all favor the idea that the minute molecules of matter are in a state of incessant movement. As nothing around us is at rest, the idea of the quiescence of the internal parts of matter would seem to contradict the whole course of Nature. The celestial bodies are in perpetual orderly movement, and it seems highly probable that at the other extreme of being there is also an order of motions equally regular and systematic.

**118.**—As heat is a molecular motion, intensity of this motion determines temperature. When a body is heated, the vibration of its molecules is augmented; the particles move through larger spaces; are urged apart, and thus cause the body to expand in bulk. When the vibrations of the particles of solids become sufficiently violent, they are loosened from the cohesion, and, continuing to oscillate as before, they are now at liberty to slip or flow around and among each other. This is the liquid state, in which rigidity has disappeared. A further augmentation of heat increases the swing of the molecules until they are thrown quite beyond the sphere of cohesion, and fly asunder into the vaporous or gaseous state.

**119. The Railway-Train.**—In this case the heat of combustion is spent in communicating to water the molecular vibration, which changes it to steam, and this molecular motion is then converted into the mechanical movement of the piston and the flight of the train. When the train is to be stopped the breaks are applied, heat and sparks are produced, and the motion of the cars is condensed back again into the molecular vibrations of heat. This explanation of the nature of heat is known as the *dynamical theory.*

**120. Heat of Combustion.**—The chief source of artificial heat is combustion. Combustion is that particular form of chemical action which takes place when the simple elements of which certain substances, as wood, coal, fats, illuminating gas, etc., are composed, enter into new combinations with oxygen, one of the constituents of our atmosphere, or any other gaseous body, with so much energy as to involve the conversion of the excess of chemical force, brought into play, into other modes of motion, chief among which are heat and light.

# CHAPTER IV.

## ELECTRICITY.

### § 1. *Frictional Electricity.*

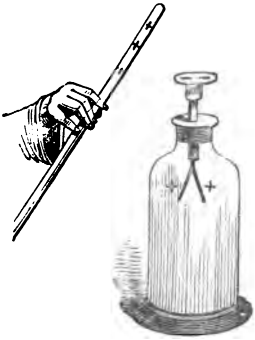
**121. Electrical Excitation.**—If a dry, warm glass tube be rubbed with a silk handkerchief, a feeble, crackling noise is heard; and, if it be dark, faint sparks will appear to dart from the surface of the glass. If the tube be now presented to any light substances, as bits of paper or feathers, they are attracted to the glass. The force or affection of matter thus made active is called *electricity.* Bodies in which it is displayed are said to be electrically excited or *electrified*, and are termed *electrics.* They are numerous, including all resinous, gummy, and glassy substances, hair, silk, dry gases, and air.

**122. Conductors and Insulators.**—Some bodies, as the metals, water, charcoal, etc., allow electricity to pass readily through them, and are hence called *conductors.* Other substances, such as glass, resins, wool, do not readily allow its passage, and are termed *non-conductors.* As the latter tend to arrest or confine electricity, they are called *insulators.* Air is a non-conductor, and acts as a universal insulator. All electrical manifestations around us depend upon this, for, if air were a good conductor, no body could preserve its electricity. Yet moisture conducts, so that the air, when charged with dampness, carries off electricity quite rapidly. For successful experiments, therefore, the air must be dry.

**123. Two Electricities.**—There are two kinds of electricity; that from glass is called *vitreous*, and that from wax *resinous*. Each is self-repulsive, but bodies excited both ways attract each other; or, as it is commonly expressed, *like electricities repel, and unlike attract.* Franklin held that bodies vitreously electrified have an excess of it above their natural share, which excess he called the *positive* state; while bodies resinously electrified are deficient in the fluid, or in a *negative* condition. The positive electrical state he distinguished by the plus sign (+), and the negative by the minus sign (—). Positive electricity is, however, no more positive, real, or powerful than negative, and the terms might be reversed so far as the character of the electricities is concerned.

**124. Electric Tension.**—The electrical excitement of a body may rise so high as to overcome the resistance which confines it and escape, rending a passage through the air, when all excitement disappears. A body electrically excited is said to be *charged;* the restoration of equilibrium is called *discharge*, and is seen in the electric spark and the flash of lightning. The degree of excitement or intensity of the charge is called *electrical tension*, and may be compared to the pressure of steam, or the bending of a bow or spring; its discharge, to their release.

Fig. 47.



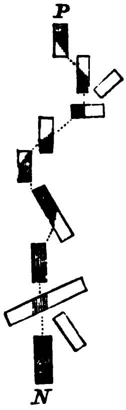
Induced Electricity.

**125. Electrical Induction.**—Electrical bodies act at a distance to disturb the equilibrium of neighboring bodies. If an excited glass rod be brought near an electroscope, though there be no contact, the gold leaves suspended in the jar below will diverge, Fig. 47, and, upon examination, it will be found that the cap is negatively electrified, and the leaves positively. The approach of the excited tube decomposes their natural electricity, the negative element being attracted, and the positive repelled. This action of an excited body, without discharge, through a medium upon distant bodies, is known as *electrical induction.*

Induction is a kind of preparation for discharge. When electricity is about to move, or discharge to occur, the whole course through which it will pass is, as it were, *felt out beforehand;* at first and infallibly the line of least resistance is found and pursued. If two conductors are before it, it takes the easiest course at the outset.

**126. Course of the Discharge.**—Fig. 48 represents fragments of gold leaves casually laid upon paper, and producing with the paper a series of bad and good conductors. A discharge finds its path across the interrupted circuit from *P* to *N*, burning up the leaves and parts of leaves, as shown by the shaded track. These remarkable results are necessary consequences of the principle of induction. The charged body induces attractions in all directions, and the discharge will, of course, be determined through that range of materials which, from their nature and position, are most excited; which present the strongest attractions, and, of course, the least obstruction.

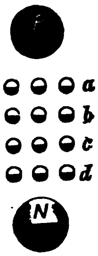
FIG. 48.



Path of the Discharge.

**127. Theory of Induction.**—As there are all degrees of conduction and insulation, Dr. Faraday held that we must look upon *conduction* and *induction* as only different degrees of the same mode of movement; in all cases, it is an effect communicated through molecules. If, when a body is electrified, its particles discharge instantaneously into each other, *conduction* is the consequence. If the molecules do not readily discharge, but hinder the course of the electricity, they are immediately forced into positions of constraint: they become *polarized*, their opposite sides having opposite properties, and, as each particle induces a state of polar tension in its neighbor, the effect is transferred to a distance. In Fig. 49, *P* represents a positively charged body, and *a b c d* intermediate particles of air. These are thrown into opposite states or polarized, as is represented by the white and black sides of the spheres, and thus the effect is propagated to the body *N*, which is electrically excited. We have said that insulators arrest electricity, but on this view they only stop movement by conduction; they transmit it by *induction* through the polarization of their particles. As the polar particles are in active relations of force to those around, it is obvious that the effects may be propagated in various directions. Hence the polarization may occur in curved lines, and induction take place round corners and behind obstacles.

Fig. 49.

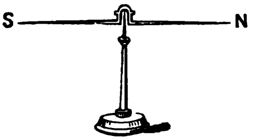


Polarization of Atoms.

## § 2. *Magnetism.*

**128. Natural and Artificial Magnets.**—If a fragment of iron-ore called the *loadstone* is suspended, it turns one of its sides to the north, and the opposite to the south; it attracts to itself particles of iron or steel, and is called a *natural magnet.* If a steel bar be rubbed by a natural magnet, it acquires magnetic properties, and becomes an *artificial* magnet. If properly shaped and poised upon a pivot, Fig. 50, it takes a northerly and southerly direction. The extremity which points northward is called the north pole of the magnet, and that which turns southward, the south pole.

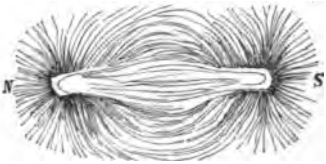
Fig. 50.



Magnetic Needle.

**129. Polarity.**—If a second needle be brought near the first, it will be noticed that they exert a powerful influence over each other. The north pole of each attracts the south pole of the other, while north pole repels north pole, and south pole repels south pole. In short, *like poles repel, and unlike attract each other.* These influences are exerted through all kinds of matter—glass, wood, metals, or the human body—and through a vacuum. The magnetic force is manifested chiefly at the poles. If a sheet of paper be laid upon a magnetic bar, and iron filings be dusted over it, on gently tapping the paper, they gather thickly around the poles, extending away in curved lines, called *magnetic curves*, Fig. 51. Thus the two magnetic forces are always produced simultaneously; are equal in amount, but opposite in direction; and as these opposite powers are manifested in the poles of the magnet, they are called *polar forces*, while the property excited is termed *polarity.*

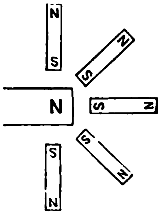
FIG. 51.



Magnetic Curves.

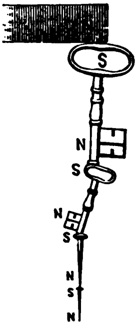
**130. Magnetic Induction.**—The preceding experiments show that the magnet has the power of exciting magnetism in adjoining bodies; in fact, each of the little particles of iron becomes a magnet with a north and south pole. This may be proved by placing several bars of soft iron around the pole of a magnetic bar, Fig. 52, when they all become temporarily magnetic. The permanent magnet *induces* the influence in the adjacent bars, which are hence said to be magnetized

FIG. 52.



Magnetic Induction.

FIG. 53.

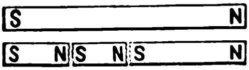


Magnetic Chain.

by *induction.* A key may be suspended by a magnet, Fig. 53, and this will hold a second smaller key, this a nail, and the nail a tack, all receiving their magnetism by induction from the bar, and each possessing its separate north and south polarity.

**131. Polarity of Particles.**—Now, the particles of the magnet are in the same condition as the magnet itself. If a magnet is broken, as in Fig. 54, and the pieces are broken again and again, the smallest particles still have opposite poles. Each particle acquires polarity, and acts by induction upon all the others, the opposite powers becoming accumulated at the opposite extremities of the bar. It may be observed that while steel *retains* its magnetism—that is, its particles remain fixed in their polar relation—soft iron, on the contrary, only remains a magnet while immediately acted upon.

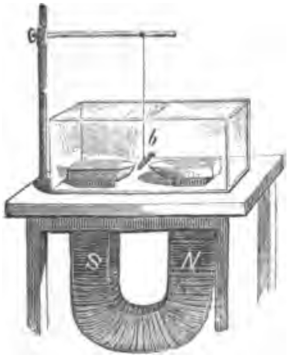
FIG. 54.



A Broken Magnet.

**132. Diamagnetism.**—Magnetic bars are usually bent in the shape of a horseshoe, and their poles are connected by a piece of iron called an *armature.* The space between the poles is called the *magnetic field;* a line joining the poles the *axis;* the line at right angles with this, the *equator.* All substances which, when freely suspended between the poles, of a magnet, arrange themselves axially, are classed as magnetic. Iron, nickel, cobalt, and oxygen, are the most important. Certain bodies, when suspended in the magnetic field, assume an equatorial direction, as if repelled by the poles, and these are said to be *diamagnetic.* In

FIG. 55.



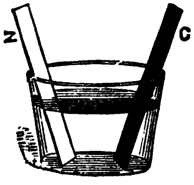
Diamagnetism.

Fig. 55, *b* represents a bar of diamagnetic bismuth suspended by fibres of unspun silk between the two poles of a magnet. This property is also manifested by antimony, wood, leather, water, etc.; in fact, all substances not magnetic are now regarded as diamagnetic.

## § 3. *Voltaic Electricity.*

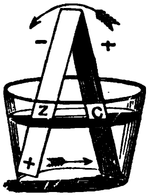
**133. The Voltaic Circuit.**—We are now to consider electricity in a form more closely related to chemical action. It was first discovered by Galvani, and has been called after him *galvanism;* but its most illustrious cultivator was Volta, from whom it is also called *voltaic electricity.* A strip of zinc and one of copper are placed in a vessel containing water, to which has been added a little sulphuric acid. If not permitted to touch each other, as in Fig. 56, there is no effect. But, if brought into contact, as seen in Fig. 57, several results ensue. The acid in the water grows weaker; the zinc strip is corroded, and bubbles of gas are seen to escape from the surface of the copper. If the metals are separated, the action ceases; and, if this is done in the dark, a minute spark will be seen. Electricity seems to flow round and round in the direction of the arrows, like an invisible stream. The combination through which it passes is termed a *voltaic circuit*, and the circulating force an electric or electromotive current. The electric current originates in chemical changes, and requires a compound liquid capable of decomposition by one of the metals.

FIG. 56.



No Effect.

FIG. 57.



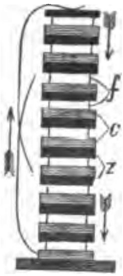
The Voltaic Circuit.

The source of the electricity, in this case, is the decomposition of the sulphuric acid forming zinc sulphate, and setting free hydrogen gas. The zinc sulphate being dissolved in the liquid, the plate is kept clean and the action maintained, till the metal is consumed, or the acid all neutralized.

**134. Electrodes.**—To the plates are often soldered wires with terminals of platinum to withstand the action of corrosive liquids. The ends of these wires are known as the *poles* of the circuit, from an idea that they exerted an attractive and repellant action, like the poles of a magnet. But Faraday has proved that there is no attraction or repulsion in the case, and suggested the better term *electrodes*, which means simply a door or way for the electricity. The copper pole is termed *positive*, and the zinc pole *negative*. Whatever be the metals used, that which is chemically acted upon and originates the electricity is termed positive.

**135. The Voltaic Pile.**—The power of the circuit may be increased by repeating its elements. The pile discovered by Volta and named after him was the first contrivance for augmenting the force of the electric current. It is made by preparing small plates or disks of metal, usually copper and zinc, and placing between them pieces of flannel moistened with an acid or saline solution. Such a pile is represented in Fig. 58. The cloth is placed between the metals, and the order begun is preserved. Commencing at the bottom there is copper (*c*), flannel (*f*), zinc (*z*), and upon that copper, flannel, zinc, and so on to fifty or a hundred sets, as may be desired (Fig. 58). The lower or copper end is positive, and the other negative; a current, therefore, moves in the direction of the arrows. This form of instrument gives a strong effect at first, but rapidly declines in power.

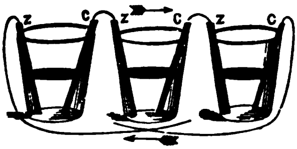
Fig. 58.



Voltaic Pile.

**136. The Galvanic Battery.**—To augment the electrical effect, and at the same time secure steadiness of action and convenience of management, the compound circuits are arranged in other forms known as *voltaic* or *galvanic batteries.* A series of vessels, called *cells,* containing an acidulated liquid, is arranged, in each of which there is a plate of copper and another of zinc; the copper plate of one cell being connected by a copper wire with the zinc plate of the preceding cell, Fig. 59.

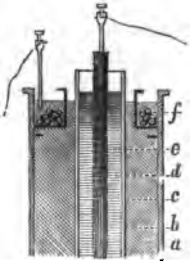
FIG. 59.



Voltaic Battery.

**137. Daniell's Battery.**—Prof. Daniell made an important improvement in the battery by using two different fluids separated by a porous partition. Fig. 60 exhibits a section of Daniell's cell: *a* is an outer cylinder of copper filled with *b*, an acid solution of blue vitriol, which is kept saturated by crystals resting upon the perforated shelf *f*; *c* is a tube of porous ware, or unoiled leather, filled with *d*, 1 part of sulphuric acid to 7 of water, and into this is plunged a rod of amalgamated zinc *e*. To the copper and zinc are attached binding screws for wire connections. When the action commences, a double set of changes takes place in the liquid. Oxide of zinc is formed in the inner vessel, and the polarizing action taking place through the porous wetted body *c*, the sulphate of copper is decomposed in the outer vessel. The sulphuric acid set free is gradually transferred to the inner vessel, while the hydrogen, instead of being set free, combines with the oxygen of the oxide of copper, precipitating metallic copper upon the surface of the outer cylinder. A variety of improved batteries, such as *Grove's* and *Bunsen's*, are now in use.

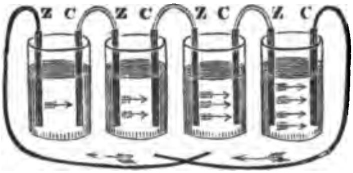
FIG. 60.



Daniell's Cell.

**138. Quantity and Intensity.**—In the battery the quantity of electricity depends upon the *size* of the plates; the intensity, upon the *number* of them. If we increase the *size* of a pair of zinc and copper plates, we increase the quantity of the electricity they produce, but not its intensity; while, if we reduce the size, we reduce the quantity, the intensity remaining the same. On the contrary, if we multiply the *number* of pairs of equal size, the intensity is augmented at an equal rate, while the quantity is unchanged. The electricity developed by a single pair is exceedingly feeble; the second cell adds no more to it, but intensifies its power. In Fig. 61 the arrows illustrate the accumulating intensity.

Fig. 61.



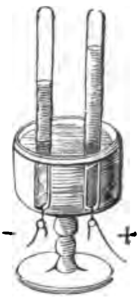
Accumulating Intensity.

**139. Induced Currents.**—If two conductors are placed near and parallel to each other, a current sent through one induces an opposite current in the second. At the moment the circuit is formed and the primary current passes, a secondary current is produced in the opposite direction in the second wire. If one or two hundred feet of stout copper wire are wound into a close coil, and then twenty or thirty thousand feet of much finer wire (both well covered with silk) be wound into a secondary coil around the first, a current sent through the inner wire, and rapidly interrupted, induces very powerful currents in the outer coil, which give rise to a stream of brilliant sparks. This is the principle of the Ruhmkorff *coil*, which has been greatly improved by Mr. Ritchie, of Boston, and is now one of the most energetic of electrical machines yet devised, producing electricity in large quantity and of extraordinary intensity.

**140.**—Voltaic electricity will travel through a conductor thousands of miles rather than penetrate a barrier of air a small fraction of an inch in thickness, while frictional electricity will leap through miles of intervening atmosphere. For sustained effects, as in chemical decompositions and telegraphy, where vast *quantities* of electricity are required, the battery is employed, its current being raised to the requisite tension by multiplying the cells.

**141. Electrolysis.**—If the ends of the platinum wires connected with a battery are placed near each other in a vessel of water containing a little sulphuric acid to aid conduction, bubbles of gas will be seen to rise from the terminals and escape at the surface. A couple of glass tubes filled with water, and inverted in the vessel over the poles, serve to collect the rising gases, Fig. 62, which, upon examination, prove to be pure hydrogen and pure oxygen, the bulk of the former being twice that of the latter. The source of the gases is the water which is decomposed. This operation is termed *electrolysis* (analyzing by electricity), and any substance that is capable of this decomposition is called an *electrolyte.*

FIG. 62.



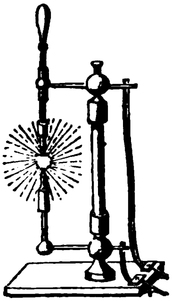
Electrolysis of Water.

**142.**—When compounds are electrolyzed, their elements are found in opposite electrical states. Some, as oxygen, chlorine, sulphur, appear at the positive electrode, and are called electro-negative bodies; while others, as hydrogen and the metals, appear at the negative electrode, and are called electro-positive. Oxygen heads the first list, or is the most powerful electro-negative body, while the newly-discovered cæsium heads the other, being the strongest electro-positive substance. The elements may be arranged in such an order that each will be electro-negative to all which follow it, and electro-positive to all which precede it. As the electric current thus originates in chemical changes and produces them, and as the atoms seem to be in opposite electrical states, it is obvious that electrical force is very closely allied to chemical power.

**143. Electrotype.**—When a salt of copper, silver, nickel, or gold, is dissolved in water, if a current of electricity be passed through the liquid, it decomposes the saline body, and the metal is deposited. In this way medals may be copied (electrotype); or new metallic surfaces may be imparted to articles, as in electro-gilding and electro-plating.

**144. Heating Effects of the Current.**—A current passing through a conductor raises its temperature in proportion to the electricity arrested. A wire which is but little heated by a current, if considerably reduced in diameter, becomes instantly white hot. The arrested electricity appears as heat. Two carbon points brought into contact in the circuit, and then slightly separated, emit a light of dazzling splendor, Fig. 63, known as the electric light.

FIG. 63.

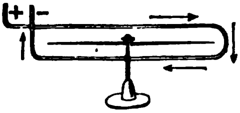


Electric Light.

## § 4. *Electricity, Magnetism, and Heat.*

**145. Electro-Magnetism.**—If a magnetic needle be brought near a wire along which an electric current is passing, the needle will be caused to move. The degree of the motion will depend upon the strength of the current, and its direction upon the relative position of the needle and wire. If the wire be above and parallel to the needle, the pole next the negative electrode will move westward; if beneath the needle, it will move eastward. If the wire is on the east side,

FIG. 64.

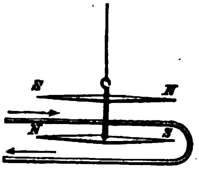


Current and Needle.

this pole will be elevated; if on the west, it will be depressed. In all cases it tends to place itself at right angles, or transverse, to the wire. If the wire be bent, so as to pass above and below the needle, Fig. 64, the effect is increased; and, if it be coiled round many times in the same manner, it becomes still more powerful.

**146. The Astatic Needle.**—A single needle keeps its place in the magnetic meridian with considerable force, so that a very faint current will not move it; but, if two needles are placed parallel, near each other, with reversed poles, their directive force is mutually neutralized. Two needles thus fixed upon an axis, Fig. 65, form the *astatic* (unstable) *needle.* If one is slightly stronger than the other, it still retains a feeble tendency to keep its north and south position. If, now, the wire of Fig. 65 were folded round both these needles, the same current would urge them in opposite directions, and there would be no motion; but, when the coil incloses only one of the needles, as the lower, for example, the current impels both needles in the same direction. If the needles be suspended by a single fibre of silk, it affords the means of detecting the faintest electrical current, and forms the *galvanometer.*

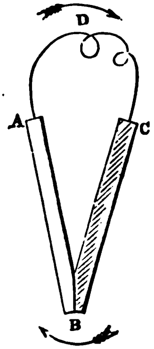
FIG. 65.



Astatic Needle.

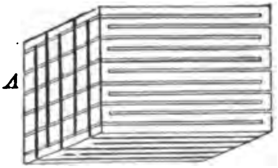
**147. Thermo-Electricity.**—Heat, applied to unlike metals when in contact, produces a current known as *thermo-electricity.* *A B*, Fig. 66, is a bar of antimony, and *B C* a bar of bismuth, soldered together at one extremity, and connected by the wire *D* at the other. When the place of junction is warmed, an electric current is produced, which moves in the direction of the arrows. If the junction *B* is chilled, the current moves in the opposite direction. Such a combination forms a *thermo-electric pair.* The effect is increased if several of these are united, forming what is known as the *thermo-electric pile.* To secure a compact arrangement, they are soldered together, and combined as in Fig 67, *A* representing one of the faces of the pile. When both faces are equally heated, there is no current. If the face, *A*, is warmed, there is a current in one direction, due to the difference of temperatures between the two faces. If the opposite face is warmed, or, what is the same thing, if the face, *A*, is cooled, there is a reverse current.

FIG. 66.



Thermo-electric Pair.

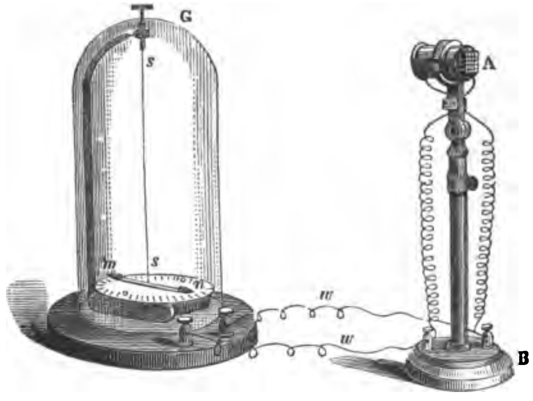
FIG. 67.



Arrangement of the Bars.

**148.** In Fig. 68, *A B* represent the thermo-electric pile as mounted for lecture-room use. *A* shows one of the faces; *w w* are wires connecting it with the galvanometer. The needle *m n* is suspended by a fibre of un-

FIG. 68.



Thermo-electric Pile as mounted for Use.

spun silk, *s s*, and protected from currents of air by the glass shade *G*. To one end of the needle is fixed a piece of red paper, and to the other a piece of blue. If the face of the pile is merely breathed upon, the warmth swings the needle round to 90°, or at right angles to the current—the pieces of paper making the movement visible throughout the room. This important instrument detects heat radiation from sources much lower than the human body, and announces the heat emitted from the bodies of insects. Lately it has been used to detect the heat from the fixed stars.

**148a. Animal Electricity.**—Certain fish possess the remarkable power of giving electrical shocks. They have internal organs for this purpose, which play the part of batteries, and the discharges from them produce all the effects of ordinary electricity. In the torpedo the electrical organs are situated on each side of the head, and consist of a mass of cells filled with a dense fluid consisting of water, albumen, and common salt. These organs give rise to electricity just as the muscles do to mechanical motion. A dense mass of nerves links them with the brain, which controls the electrical discharges in the same way as it does the mechanical movements.

It has been proved that currents of electricity circulate in the frames of all animals, and that different parts or sections of the muscles are in different electrical states. The smallest shreds of muscular tissue have been proved by Prof. Du Bois-Raymond to manifest currents, the longitudinal section being always positive to the transverse section. By arranging a series of half-thighs of frogs, alternately connecting the exterior and interior surfaces, he obtained an electrical current that decomposed potassic iodide, deflected a magnetic needle 90°, and caused the gold leaves of an electroscope to diverge. Many have supposed that the nervous force is electrical, but this is disproved by the comparatively slow rate of its motion. It is, however, probably an analogous polar force.

# CHAPTER V.

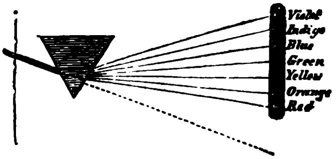
## LIGHT.

### § 1. *Motion of the Radiant Forces.*

**149. Their Motion.**—Light is that agent which, acting on the eye, produces vision. Other forces are generally associated with it that obey the same laws of motion; and, as that motion is in *rays*, they are known as radiant forces; their laws of movement are the same. Light moves in straight lines and in all directions from the point of emission—diminishing in intensity in inverse ratio to the square of the distance. Its velocity is about 190,000 miles per second. When light falls upon bodies, some reflect it, others absorb it, and others transmit it. The laws of these motions are explained in books upon optics.

**150. The Analysis of Light.**—By the *prism*—a triangular piece of glass, or other transparent substance—the white ray is decomposed into a series of colors. A beam of solar light passing through such a prism, Fig. 69, is refracted by it, and produces an oblong colored image called the *solar spectrum*. It is usually considered to comprise the seven colors enumerated in the accompanying diagram. White light is, therefore, held to be a compound consisting of these colored lights, which are only *separated* by the prism. Each color has its own peculiar

FIG. 69.



Decomposition of Light.

refrangibility, or degree of divergence from the original source, the *red* being least refracted, and the *violet* most. Certain of the rays accompanying light produce heating effects, and others chemical effects. These rays are governed by the same laws of motion as light itself, but by the prism the heat is mainly distributed through the red end of the spectrum, and the chemical force through the violet extremity. (162.)

**151. The Wave Hypothesis.**—The motion of the radiant forces is explained by what is called the *wave-theory.* It is known that sound is propagated through the air by means of the vibration of its particles; and it is supposed that light moves by a similar mode of action. There is a great amount of evidence to show that the radiant forces are propagated by some kind of undulatory movement, but the hypothesis implies a medium that is capable of this kind of motion. This medium is assumed to be an infinitely rare and elastic ether that fills all space and pervades all matter.

**152. Cause of Colors.**—According to this *hypothesis*, light is transmitted by ethereal undulations just as sound is by those of the atmosphere; with only this difference, that, while the air-particles move backward and forward in the same direction as the advancing wave (*longitudinal vibrations*), the ethereal particles move across the course of the wave (*transverse vibrations*). Thus the spectrum is to the eye what the gamut is to the ear. As the pitch of sound depends upon the length of the air-wave, so the color of light depends upon the length of the ethereal wave; and as loudness of sound depends upon the extent of the swing of air-particles, so the brightness or intensity of color results from the extent of the excursions of the ethereal particles.

By several refined methods which cannot be detailed here, the lengths of the ethereal waves upon which colors depend have been estimated. The motions which produce red are slower, and the undulations longer than those which produce violet. It is found that 40,000 waves of red light would measure an inch, while 60,000 waves of violet light would fill the same space. The other colors are intermediate, their number of waves increasing gradually from red to violet. As light moves 190,000 miles per second, that length of ray streams into the eye each second. If this distance be reduced to inches, and the product be multiplied by 40,000, we shall have the number of waves which beat against the retina each second, when we look upon a red color. If the same product is multiplied by 60,000, we get the number of pulses per second which strike the retina when looking upon a violet color.

**153. Transmission of Radiant Motion.**—In this view it is necessary to distinguish between vibrations and undulations. In the case of sound, the vibrations of a sonorous body, as a bell, produce undulations in the air which, when striking against distant bodies, may set them also into vibration. The vibrations of the bell, transmitted as air-waves, are taken up by the tympanum of the ear, which, when set to vibrating, gives rise to the sensation of sound. So the vibration of atoms in a flame produces undulations in the ether; these are transmitted to the nerve of vision, and, breaking against it, throw its atoms into the vibrations which produce sight. In the same way the particles of a heated body are supposed to be in a state of vibration, which are transmitted by ethereal undulations, and these, falling upon other bodies, set their particles into vibration, and raise their temperature. This is the explanation afforded of radiant heat.

## § 2. *Interference and Polarization.*

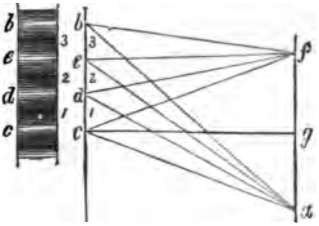
**154. Interference of Waves.**—When two sets of water-waves are made to flow together, if they coincide, that is, if ridge corresponds to ridge, their height will be *increased;*

but, if the ridge of one corresponds with the trough of another, they will *neutralize* each other, and the water become still. This is called *interference.*

Again, two stretched strings, or two tuning-forks, may be so placed, that, when simultaneously struck, they do not give forth a continuous sound; but there is produced a series of alternating swells and depressions of tone. During the pauses, there is still rapid vibration, so it is certain that the sounds are extinguished by interference of their waves.

**155. Interference of Light.**—If a beam of *colored* light be admitted into a dark room by two pinholes made near each other in a thin sheet of metal, and be made to fall upon a screen at a short distance, the rays intersect each other, and a series of dark bands alternating with bright stripes will be formed upon the screen by interference of the ray from the two orifices. In Fig. 70, *a f* represent the two pinholes, and *c d e b* a portion of the screen, *c g* being a line joining the two surfaces at right angles, and midway between the pinholes. The rays, *a c*, *f c*, pass through equal paths; their waves coincide at *c*, and, heightening each other's effect, a bright band is produced at *c*; *a d*, *f d* will differ by the length of one wave, *a e*, *f e* by the length of two waves, and *a b*, *f b* by the length of three waves; hence, there will be also bright bands at *d*, *e*, and *b*. But the rays from the two orifices, meeting at 1, 2, 3, differ in length successively by half a wave, a wave and a half, and two waves and a half, and, by thus interfering, extinguish each other and produce darkness. As the rays which meet at *c* are equal, it is obvious that all the other rays coming

FIG. 70.



Interference of Light.

from *a* are lengthened, and all others coming from *f* are shortened. As this variation of length is gradual, there will be a gradual passage from the brightest light to complete darkness. This effect is exhibited by the shaded portion of the diagram. If the light from one aperture is intercepted, all the dark bands disappear.

Thus we have seen that motion added to motion produces rest; that sound added to sound produces silence; that light added to light produces darkness; and it has also been proved that heat added to heat produces cold, heat-rays being liable to interference, like light.

**156. Polarization of Light.**—When light is reflected at certain angles from the surface of glass, water, marble, polished wood, etc., a portion of it undergoes a remarkable change. Although taking place all around us constantly, we do not perceive it, but it may be detected in various ways. Two plates of glass are blackened on one side so as to have but a single reflecting surface, and then placed as shown in Fig. 71, *a*, *b*, with their edges toward the eye. A ray of common light falling upon *a* in the direction of the arrow is reflected, and, upon being thrown upon *b*, is again reflected. The ray is changed at *a*, as the altered structure of the line shows, but the effect is not apparent. If now *b*, or the second plate, is turned a quarter round, its angle with the ray being preserved, reflection ceases, and the beam is extinguished, Fig. 72. Turning it another

FIG. 71.

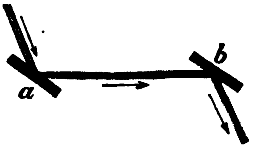


FIG. 72.

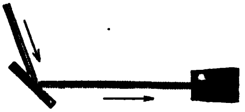


FIG. 73.

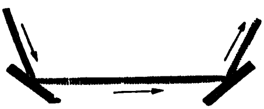
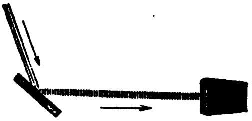


FIG. 74.

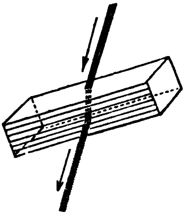


Light polarized by Reflection.

quarter round, Fig. 73, the ray is again reflected; and still another quarter revolution, Fig. 74, brings it on the opposide side to Fig. 71, and again extinguishes it. The beam may be reflected from surface to surface any number of times *in the same plane;* but it has lost the ability of being reflected in planes *at right angles* to that plane, while common light may be reflected in all directions. It thus appears that the ray has acquired *different properties on different sides.* From its analogy to magnetic polarity, this change is called *polarization*, and the ray thus affected is said to be *polarized.* The angle at which the ray falls upon the polarizing surface is called the *polarizing angle*, and differs in different substances: for glass, it is 56° 45′, while for water it is 53° 11′.

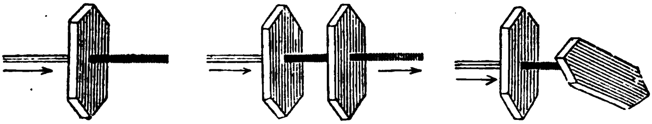
**157. Polarizing by Transmission.**—Light transmitted obliquely through a bundle of thin glass plates, Fig. 75, is polarized, and the same effect is also produced by its passage through certain crystals. A stone, called the *tourmaline*, is much used for polarizing purposes. A thin polished plate of it polarizes the light which passes through it, as in Fig. 76. If a second plate is placed parallel to the first, Fig. 77, the light passes through both; but if the second plate is turned a quarter round, Fig. 78, the light is stopped. "The rays of the meridian sun cannot pass through a pair of crossed tour-

FIG. 75.



Polarization by Thin Plates.

FIG. 76. FIG. 77. FIG. 78.

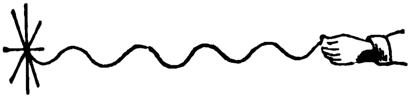


Polarization by Tourmalines.

malines." The plate polarizing the light is called a *polarizer;* that which tests or detects it after it, is changed, is termed the *analyzer.*

**158. Theory of Polarization.**—The wave-theory thus explains the phenomena. We can vibrate a cord up and down, horizontally, or in any direction transverse to its length, Fig. 79. In common light the undulations take place practically in *all* these directions at once. It has been suggested that common light may be represented by a *round* rod; polarized light by a flat lath. Supposing the round rod to image to us the common ray, the radii, Fig. 80, will exhibit the system of transverse vibrations taking place in all planes. But the effect is just the same if we regard the vibrations as taking place in *two planes* only, at right angles to each other, as in Fig. 81. Now, when common light is reflected in certain positions, which we have just noticed, one of its planes of vibration is destroyed, and the beam is polarized, *its vibrations taking place all in one plane,* Fig. 82. We can now easily understand the action of the tourmaline upon light. A plate of this crystal suppresses one of the planes of vibration, and therefore transmits a polar-

FIG. 79.



Vibration in Different Planes.

FIG. 80.

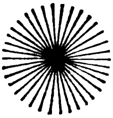


FIG. 81

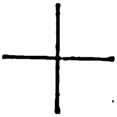
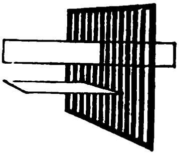


FIG. 82.

Illustrations of Planes of Vibration.

FIG. 83.

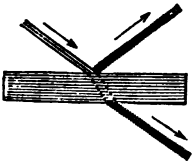


Motion in a Single Plane.

ized ray. This will pass through a second plate if it is held in such a manner that its structure coincides with the motion; but, if it is turned so as to cross the waves, the ray is obstructed. A card which readily slips through a grate when its plane coincides with the bars, will be stopped if it is turned a quarter round, Fig. 83.

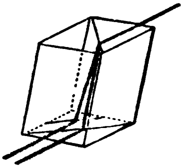
**159.**—When a ray falls upon a transparent surface at a certain angle, its planes of vibration are *resolved into two*, one of which is reflected, and the other transmitted, Fig. 84; both are polarized, but one ray vibrates in one direction, and the other at right angles to it.

FIG. 84.



Polarized Rays.

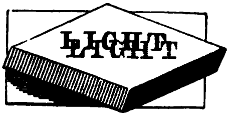
FIG. 85.



Double Refraction.

**160. Double Refraction.**—Some substances possess the singular property of splitting the ray which passes through them, producing an effect which is known as *double refraction*, Fig. 85. Iceland spar and many crystals possess this power; printed words, or a candle-flame, seen through them, appearing double, Fig. 86. The effect is supposed to be due to the molecular structure of the body.

FIG. 86.



Effect of Double Refraction.

**161. Phosphorescence.**—This is a property possessed by various bodies of emitting a faint light at ordinary or low temperatures, and is so named from phosphorus, which exhibits it in a remarkable degree. Phosphorescence is manifested by certain insects, as the firefly and glow-worm, by several species of plants, by various animal and vegetable substances in a state of decay, and by exposure of many substances to sources of light. If calcined oyster-shells be placed for a short time in sunshine, and then withdrawn into darkness, they will continue to glow for some time, while other bodies, as the diamond and chlorophane, after exposure, remain for a long time luminous. Recent investigations have shown that the same property exists in a much lower degree in a great number of bodies, their phosphorescence continuing in most cases for the briefest moment—sometimes only for the ten-thousandth of a second. It would seem that, in cases where the luminosity continues, the molecules of matter are set in motion by the ethereal undulations, and continue to move after the withdrawal of the exciting cause. *Fluorescence* is a kind of phosphorescence, in which the highly-refrangible dark rays of the solar spectrum, next to be considered, are turned to light when falling upon certain substances, as fluor-spar, or sulphate of quinine solution.

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# CHAPTER VI.

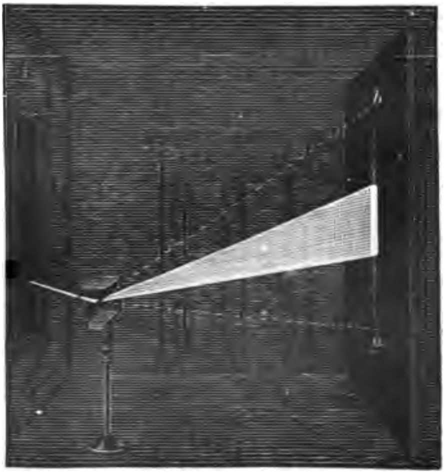
## THE CHEMISTRY OF LIGHT.

### § 1. *The Chemical Rays.*

**162. A Third Radiant Force.** — Besides the heat-rays, which take effect upon all kinds of matter, and the luminous rays, which act only upon special forms of nerve-substance producing the sensation of vision, there is a third class of rays which act upon certain chemical bodies, producing combination and decomposition. These have been called *actinic* rays, and the agency *actinism;* but they are better known as chemical rays. They accompany the light of the sun and stars, and are produced in artificial illumination; but they are, nevertheless, distinct from light. The art of photography depends upon them, and has given a great stimulus to their recent investigation. Like light and heat, the chemical radiations are measurable in their effects, and have given rise to an independent branch of scientific inquiry.

**163. Refrangibility of the Invisible Radiations.** — The heat-rays and the chemical rays are reflected and refracted like light, and like the colored rays they exhibit marked differences in their degrees of refrangibility. When the sunbeam is passed through a prism (Fig. 87) not only is there an oblong visible image thrown upon the screen, but there is also an invisible heat-image, and an invisible chemical image, which are revealed in different ways. The position and varying intensity of the heat-spectrum may be traced out by a delicate galvanometer, and it is found that it begins down in the neighborhood of *a*, and runs up into the luminous region. A large portion of the heat-rays are hence of a lower refrangibility than the red, and are dark radiations. If, now, a solution of argentic nitrate is washed over a large sheet of paper, which is then placed upon the screen so as to receive the visible spectrum and extend through the space

FIG. 87.

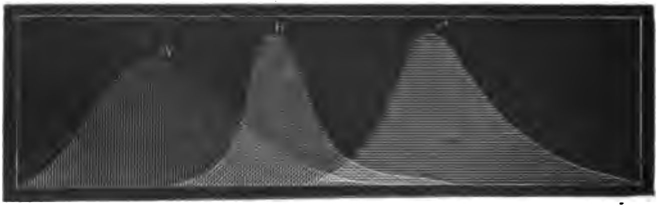


Positions of the Three Spectra.

above it, a chemical change takes place upon its surface, producing a blackening, which defines the outline of the chemical spectrum. It is now found that the chemical rays are more refrangible than the luminous; and that, while the blackening takes place in the colored spectrum, it extends also through the dark space up to *b*. That the heat of the spectrum is greatest in the red, and that there are dark thermal rays of still lower refrangibility, was shown by Sir William Herschel, in the year 1800. That the chemical rays of the luminous spectrum are most active in the violet region was pointed out by Scheele, in 1777; while their extension into the dark space beyond, was discovered by Ritter, in 1801.

**164. Distribution of the Forces.**—The forces of the spectrum are thus very unequally distributed, as is illustrated in Fig. 88, where they appear to rise like the peaks of mountains. The middle curve shows the varying intensity of the luminous force. The maximum is at *B* in the yellow space, and from this point the intensity of the light rapidly declines each way; its extent being shown by the space shaded with oblique lines. The curve *A*, with the vertical lines, represents the position and varying force of the heat; and the curve *C*, horizontally shaded, exhibits the distribution and unequal energy of the chemical force. The three maxima are widely separated, as if there were some antagonism among them; and it is noticeable that where the light is strongest the chemical force seems quite

FIG. 88.



Varying Intensities of the Spectrum Forces.

neutralized. Different kinds of prisms (180) give somewhat different effects, but do not change their order.[1] The mode of action of all these radiations is unquestionably the same. Heat-rays, light-rays, and chemical rays, differ from each other only as yellow differs from green, that is, by wave-length and intensity of vibration. They all exhibit the effects of interference and polarization which proves the mode of ray-action to be alike in all.

**165. Actinometry.**—It has been stated that the chemical rays are measurable in their force, and for this important step of research we are indebted to Dr. J. W. Draper. If hydrogen and chlorine gases be mixed in equal proportions in a glass vessel, and kept in the dark, they will not combine ; but, if exposed to the light, they unite with each other, forming a compound. Upon such a mixture, however, the red rays produce no effect, while the violet rays cause the gases to combine explosively. It is the chemical rays that are here active, and Dr. Draper employed a mixture of these gases to test, by the rate of combination, the varying intensity of the force. Instruments for this purpose have been called *actinometers*. Roscoe and Bunsen afterward employed papers, made sensitive by silver nitrate, which were blackened in given times to certain shades as standard tests of the varying force of the chemical rays.

**166. Variation of Chemical Rays in England.**—Observations were made at the Kew Observatory, near London, to determine the changes of chemical activity in the solar rays at different hours of the day, and different seasons of the year. The diagram (Fig. 89) represents the results graphically. The experiments were made from 6 A. M. to 6 P. M. throughout the year 1866. The figures below give the hour of the day, and each curve represents the daily change in intensity for the average of a month—the horizontal lines marking the scale of effects. The maximum effect occurs at twelve o'clock, and the forenoon rise and afternoon decline are very nearly equal. But by comparing the highest and lowest curves it will be seen that the chemical intensity was fully seven times as great in July as in December.

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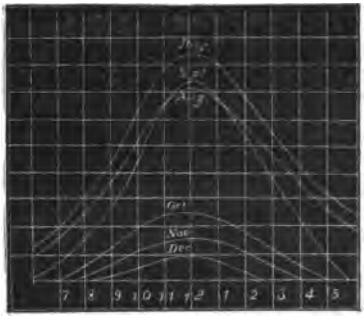
[1] See note on this subject in the Appendix.

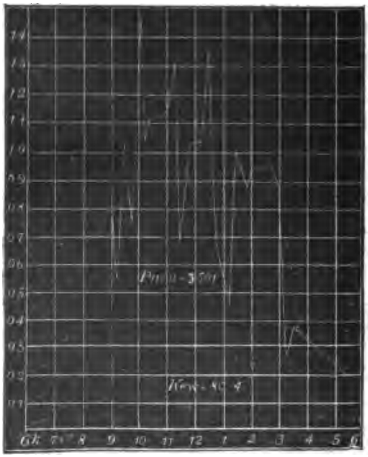
FIG. 89.



Curves of Variation at Kew.

**167. Effects at the Equator.** — As we go south, though the light increases in brilliancy, the chemical action is impeded or interfered with, so that it is said to take ten or twenty times longer to get a picture under the blaze of the Mexican sun than in New York. Yet the effect seems not due to lack of intensity of the chemical rays, but, perhaps, to some obscure cause of irregular action. Fig. 90 represents the effects obtained at Pará, in North Brazil, situated nearly under the equator. The zigzag lines show the sudden changes of intensity from hour to hour, which were accompanied by heavy showers. The dotted line below represents the chemic alresults at Kew at the same time.

FIG. 90.



Fluctuations at the Equator.

**168. Relation to Vegetation.**—Of the effects produced by these rays in Nature little is understood. It has long been known that light exerts a powerful influence upon the organic world. Vegetation languishes in the absence of light, and flourishes when exposed to it. It was at first supposed that this power over plants resided in the chemical rays; but it is now known that the force that decomposes carbon dioxide in green leaves, and which is the foundation of the vegetative processes, is most active, not in the blue, but in the yellow space of the spectrum, where the actinic force is absent.

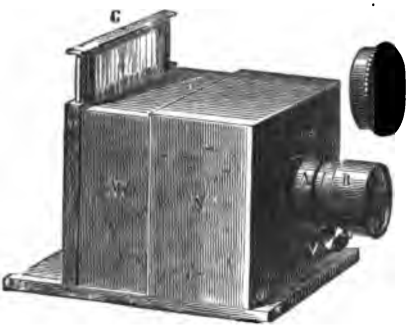
## § 2. *Photographic Chemistry.*

**169. Chemical Reactions of Light.** — It was long supposed that the chemical rays act only upon a few substances, but the contrary is really the fact. So many substances are affected by it, and in so many different ways, that some think a ray of light cannot fall upon the surface of any solid without impressing upon it an enduring molecular change. Four kinds of effect may be here referred to: First, the elements, such as phosphorus, are altered by light in their allotropic forms (271). Second, light promotes chemical combination of the elements, as already shown (165). Third, it produces mechanical effects. If the beautiful ruby-colored crystals of arsenic disulphide are exposed to light for some months, they become pliant and fall to powder. Fourth, chemical compounds, as silver nitrate, are decomposed under the influence of light, and new compounds are formed.

**170. Substances at the Basis of Photography.** — By exploring this subject, chemists have founded a new art of great importance, that of taking pictures quickly, cheaply, and accurately, by the direct action of light. Experimenters began to feel their way toward this result early in the present century; but the process only became successful in the hands of M. Daguerre, a Frenchman, who made it public in August, 1839; and since then it has undergone the most rapid extension and development. For photographic purposes the salts of silver are mainly used—silver iodide, bromide, and chloride, being the substances most generally employed. The unequal susceptibility of these compounds to the action of light gives great resources to the operator, and is the basis of this modern art.

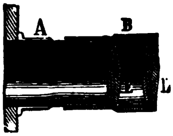
**171. Production of the Invisible Image.**—Photographic pictures are taken, as is well known, by means of a *camera-obscura*, an instrument by which inverted images of external objects are produced in a dark chamber in their natural colors. In Fig. 91 *G* represents a ground-glass slide upon which the image is formed, and which is viewed by the operator from behind. The glass plate is brought to the exact focus, first by sliding the part *M* of the box in the part *N*, and then by turning the pinion *V*, which moves the lenses in the tube *A B*. Fig. 92 represents the lenses *E L* in the tube *A B*; two lenses having the effect of allowing a larger aperture, and increased light, with the same focal distance. A metallic or glass plate is then prepared in an obscurely lighted place, by coating it with the proper chemicals, and it is then said to be *sensitive*; that is, it is very susceptible to changes from the action of light. It is, therefore, kept protected from the daylight, until substituted for the glass slide *G* in the camera. The cap being then removed from be-

FIG. 91.



Photographic Camera.

FIG. 92.



Position of Lenses.

fore the lenses, the light from the object to be taken falls upon the sensitive surface. If silver iodide be used, such as Daguerre employed, twenty minutes will be necessary to get an impression. But if silver bromide, or chloride, be used, which are far more sensitive, the operation is quickened, and by mixing different chemicals any degree of sensitiveness may be secured. If required, an impression may be obtained in the hundredth part of a second.

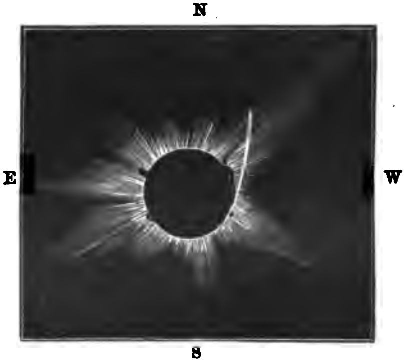
**172. Developing the Picture.** — When the plate is removed from the camera, no effect is visible; the image has to be brought out or *developed* by a subsequent process. Daguerre effected this by exposing the plate to vapor of mercury, which, being condensed unequally upon the changed surface, evolved the lights and shadows, that became visible when the plate was washed with sodic hyposulphite, by which the unchanged silver iodide is dissolved away. At present the plates exposed in the camera are coated with collodion, in which the sensitive chemicals are contained. The pictures are developed by washing the surface with a solution of green vitriol, which, becoming mixed with the silver compounds, decomposes them, and precipitates the silver in the form of a fine black powder, that adheres to the exposed surfaces of the plate.

**173. Negatives and Positives.**—Pictures are now generally taken upon a transparent glass plate, in which the lights and shades are reversed, and these are called *negatives.* But from these negatives others are taken, and the effects are again reversed, which makes them true to nature—lights answering to lights, and shadows to shadows: these are called *positives.* They are copied, or printed from the negative, by placing sensitively-prepared paper surfaces against the negative, and exposing to sunlight. In this way, from a single negative, many positives may be obtained, while a little delicate retouching of the negative, with Indian-ink or a pencil, may remove defects, and improve all the positives printed from it. This is often desirable, as freckles and pimples upon the face are liable to be exaggerated in the photographic negative.

**174. Varying Effect of Colored Lights.**—Yellow and reddish light being chemically inoperative, the artist can carry on his manipulations by a dingy lamp-light or daylight passing through yellow glass; and as blue light is chemically most powerful, the reflected illumination of the sky is favorable for photographic effects. White clouds increase the chemical intensity of light, while gray clouds diminish it. Blue, indigo, and violet colors generally come out light in photographs, while yellow and red work dark. Hence dark-blue flowers on a light-yellow ground produce light flowers on a dark ground. Red, and also fair golden hair, becomes black, and yellow specks in the face produce black points in a picture. It is obvious from this unequal working of light that many-colored toilets must produce discordant photographic results. "Persons of dark complexions, also stout persons, should prefer dark clothes; as it is well known that white clothing increases in appearance the fullness of the figure. Thin and pale persons are advised, on the contrary, to wear light clothes, as a pale complexion would appear even paler when contrasted with black."—(Vogel.)

**175. Celestial Photography.**—The applications of photography in the arts are becoming constantly more valuable, and it is also an important resource of science in making quick and accurate representations, and in recording the workings of self-registering apparatus. Its astronomic indications are of especial interest. Enlarged photographs of the moon represent the details of its surface with surprising minuteness; and photographs of the stars are taken, which define their position with the greatest accuracy. In observing eclipses of the sun, this power of producing instantaneous pictures is invaluable; for the display in a total solar eclipse is grand, complex, and momentary—chromosphere, prominences, and corona, all burst upon the view at once, and baffle every attempt at delineation. The corona is a vast, irregular luminous appendage surrounding the sun, reaching away to immense distances, only visible in eclipses, of unknown nature, and presenting the greatest diversity of aspects at different times. Photography is therefore eminently adapted to seize its peculiar and varying appearances. Fig. 93 represents a picture of the eclipse of 1868, taken in a few seconds, and selected because its aspect is very marked. The great coronal halo is seen to have the appearance of rays, with deep gaps or rifts; and the curious effect of an oblique luminous line cutting the lower stratum of light was recorded upon the plate. Other photographs give a more even outline, and a wider circle of white light around the central body. The multiplication of such impressions in different places, and at different times, will be of the utmost service in the investigations of solar physics.

FIG. 93.



Photograph of Total Solar Eclipse of 1868.

## CHAPTER VII.

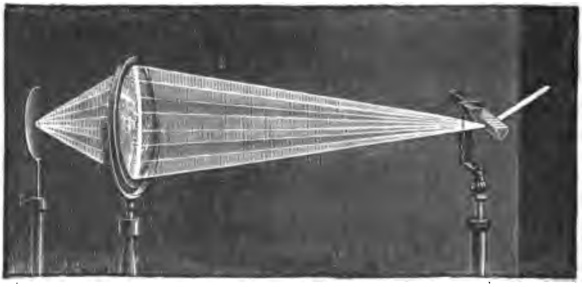
### SPECTRUM ANALYSIS.

**176. Interest of the Subject.**—The progress of science is full of surprises. A step is taken that seems so wonderful that nothing can surpass it; but it is soon eclipsed by something still more wonderful. With the remarkable discovery that the radiations of space can produce enduring images by the chemical alterations of matter, it was thought that the marvels of light were exhausted; but, twenty years after photography, came spectrum analysis—the most brilliant and startling of all modern discoveries. It has endowed the chemist with a power of research of hitherto unapproachable delicacy, by which new elements have been discovered, and our knowledge of the composition of matter greatly extended and refined. And, what is much more astonishing, it has revealed the chemical elements in the atmospheres of the sun and the stars; and thus made chemistry a cosmical instead of a terrestrial science. In spectrum analysis, chemistry and physics become most intimately united, so that an account of it becomes necessary before closing the subject of Chemical Physics.

## § 1. *The Luminous Spectrum.*

**177. Newton's Experiment.**—The analysis of the solar beam into its elemental colors by the prism has been referred to in speaking of the general properties of light (150): we have now to study the spectrum more carefully.

FIG. 94.

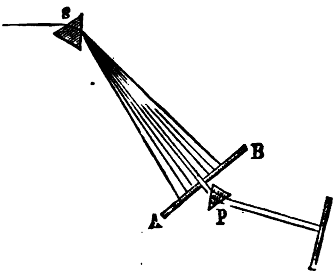


Recomposition of Light by a Lens.

Spectral phenomena, as seen in rainbow-tints, in the sparkle of jewels, the chromatic flashes of cut-glass, and the gleaming hues of clouds at sunset, have ever been familiar; but they were first explained by Newton in his treatise on optics, presented to the Royal Society in 1675, exactly two hundred years ago. He showed that white light, in passing through the prism (Fig. 69), is resolved into its elements, forming a splendid colored image, such as is shown in the plate at the beginning of the volume. This is proved by reversing the process. If the separated colored rays are recombined by a lens, as illustrated in Fig. 94, they reproduce the spot of white light.

**178. The Solar Spectrum.**—The colors produced by prismatic analysis are ultimate elements. Those seen in the perfect solar spectrum are in the highest degree brilliant and pure. They blend with each other in imperceptible gradations, so that their number and limits are indeterminate. For convenience they are designated as forming seven principal groups; but, as Baden Powell remarked, "the fact is, the number of primary rays is not really seven but infinite." That the colors produced are incapable of further decomposition may be shown by passing a beam of the spectrum through a second prism, as represented in Fig. 95. The white ray refracted by the prism, *S*, gives the spectrum on the screen, *A B*. If, now, an aperture is made in the screen, and a colored pencil passed through a second prism, *P*, it will not be further analyzed, but only diverted in its course.

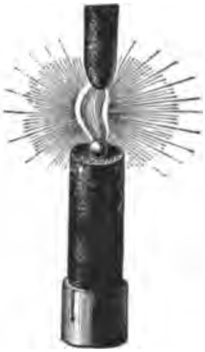
Fig. 95.



Effect of Second Prism.

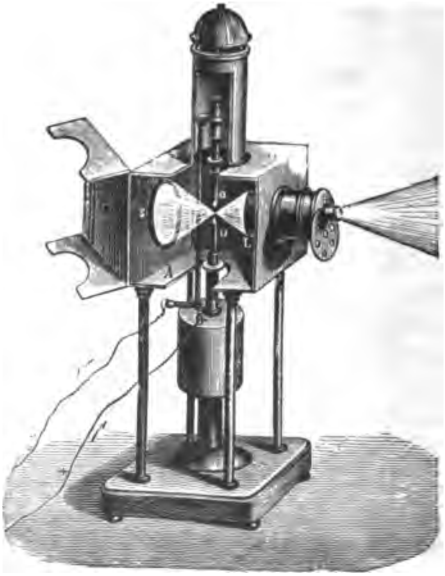
**179. Spectrum of the Electric Light.**—Any source of light may be employed to produce a spectrum; but next to the sun, which is by far the most brilliant, the spectrum of the electric light is most powerful, and is generally used where intense effects are required. If two carbon cylinders (Fig. 96) are brought near each other, and the current of a powerful voltaic battery be sent through them, the stream of discharge takes the form of a brilliant arc of fire between the points with the emission of a dazzling light. This has to be inclosed in a box or lantern, one of the forms of which is shown in Fig. 97. As the carbon-points gradually waste away, the distance between them would become too great, and they are kept in the proper position by the machinery of the lamp. The intensity of the light from the voltaic arc depends chiefly upon the amount of electricity generated, and the purity of the carbon-points. Measured by its chemical effects, it has been found that the electric light from a Bunsen battery of forty-six elements has nearly one-fourth the intensity of sunlight at noon in August. The electric light is convenient for displaying the spec-

Fig. 96.



Electric Arc

Fig 97.

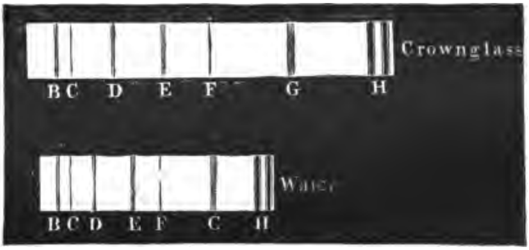


Electric Lamp.

tra produced by various substances. Fig. 96 shows a piece of sodium placed for volatilization on the lower carbon.

**180. Dispersion.**—Although in prismatic analysis the colors are always refracted in the same order, yet different substances have very unequal refractive power, and separate the rays unequally. The degree of separation is called *dispersion.* The dispersive power of water is low. A hollow prism filled with water gives a short spectrum, as shown in Fig. 98 (the lettered lines of which will be presently explained). The dispersion is seen to be much greater with a prism of crown-glass. Again, the dispersive power of a prism of flint-glass is twice as great as one of crown-glass: and a hollow prism filled with bisulphide of carbon gives a spectrum twice as long as that of flint-glass. The denser the glass the greater the dispersion; and the greater the angle in prisms of all materials, the greater also is the dispersion. But the spectrum loses in sharpness and brilliancy, in proportion as it is extended.

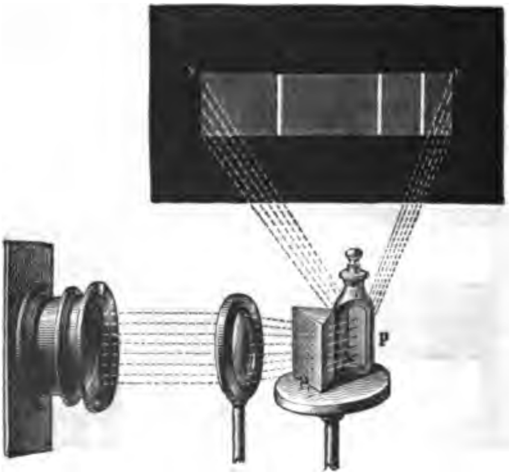
Fig. 98.



Unequal Dispersion.

**181. Combination of Prisms.**—Dispersion may be increased by adding one prism to another in such a way that the refracted light of the first shall pass on through the second. Fig. 99 shows how this may be effected. The electric light emerging through a slit, is directed by the double-convex lens upon a flint-glass prism, and having undergone one refraction, falls upon a second prism *P* filled with bisulphide of carbon, which then forms the image *V R* upon the screen. The image is seen to be diverted more than 90° to one side. With a spectrum thus produced, eight feet long, the colors would be distinguishable, but will have lost much of their brilliancy.

FIG. 99.



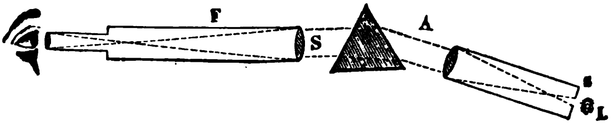
Spectrum formed by Two Prisms.

**182. Trains of Prisms.** — For the usual purposes of examination, a single prism suffices; but, in delicate researches, it is often desirable to increase the dispersion to a high degree. This is especially the case in working with the feeble light from the stars, comets, nebula, and the aurora. Three, four, and sometimes a dozen prisms, are therefore combined when such delicate observations are required; and the whole effect may be doubled by reflecting the light back through the same train, as will be shown when we come to speak of the applications of the spectroscope to celestial bodies (204).

## § 2. *The Spectroscope.*

**183. Its Essential Parts.**—The spectroscope is an instrument for observing the spectrum. Fig. 100 shows its simplest form, and the relation of its parts. *L* represents the light, which may be from any source, natural or artificial, the spectrum of which is to be examined. *A* is a tube, closed at *S*, but in the end of which there is a vertical slit, opened and adjusted by a slide or screw (205). This slit is a very important part of the instrument, and is formed by knife-edges of the most unchangeable material, finished with great accuracy, so as to give a perfect line, though not more than $\frac{1}{300}$ of an inch in thickness. The light entering the slit, passes through a tube called the collimator, containing a lens, by which the rays are made parallel before falling upon the prism. The rays emerge from the opposite face of the prism refracted, yet only slightly dispersed, so that the spectrum *S* is but little larger than the width of the slit. In order to observe it of a sufficient size, at a short distance, a magnifying-glass or small telescope, *F*, is employed. The collimator, the prism, and the spy-glass, are therefore the essential parts; and in use the prism requires to be covered to exclude the interfering light.

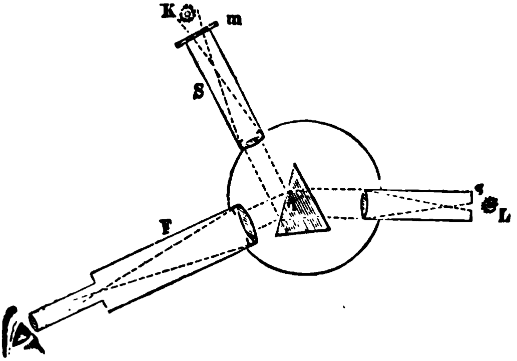
Fig. 100.



The Simple Spectroscope.

**184. Measuring the Spectrum.**—But for scientific purposes the instrument requires the most accurate means of measuring the spaces of the spectrum. For this purpose a third tube has been added, as shown in Fig. 101 at *S*. At its outer end there is a glass plate, *m*, upon which is engraved or photographed a scale of minute divisions. A lamp, *K*, throws the image of this scale through the tube and lens, so that it falls upon the face of the prism at *n*, at such an angle as to be reflected by the polished surface of glass through the telescope *F* to the eye. The scale is permanent, and parallel with it the observer sees the spectrum of whatever light is employed, and can thus fix and compare the position of the lines with exactness.

FIG. 101.

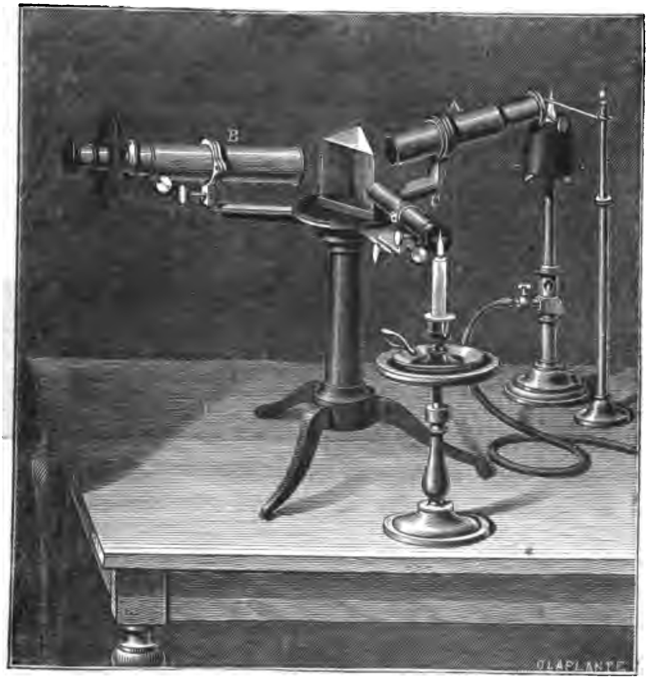


Compound Spectroscope.

**185. The Mounted Instrument.**—The foregoing figures show a mere skeleton of the parts, for explanation: Fig. 102 represents the construction of the instrument as ready for use. *A* is the collimator-tube, the slit not being visible. A gas-burner is represented as the source of light; and a stand is shown beside it, with an arm for supporting in the flame any substances it is desired to experiment with. *B* is the telescope furnished with a guard to screen the eye from extraneous light. *C* is the tube with the scale for measurement, and a candle for projecting the image.

**186. Direct-Vision Spectroscopes.**—It would obviously be an advantage if the slit, lens, prism, and telescope, were all in a straight line, so that the instrument could be applied directly to the light to be examined. This result is gained in the direct-vision spectroscope. If two exactly similar prisms are combined in opposite positions, as in Fig. 103, *A B*, the changes impressed upon a ray by the first will be counteracted by the second. But, if the prisms differ in refractive angles, or density of material, this counteraction will not be complete. The *deviation* may be corrected, which will give a straight path for the light, but the *dispersion* may be but partially corrected, which will leave a spectrum. This depends upon the principle that the disper-

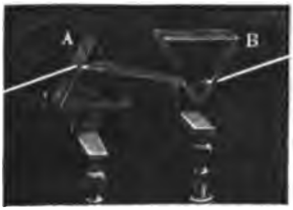
FIG. 102.



The Common Mounted Spectroscope.

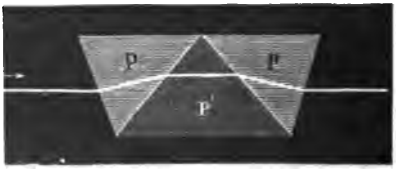
sive power of various kinds of prisms is not exactly in the proportion of their refractive power. Hence, if two crown-glass prisms, *P P* (Fig. 104), are combined with a flint glass prism, *P'*, of greater angle, and in a reversed position, the combination will give a spectrum in the line of sight. A train of prisms thus arranged, and combined with a spyglass, forms the direct-vision spectroscope, which is shown mounted upon a stand, *S*, in Fig. 105. It may be detached from the stand, unscrewed at the centre, and placed in a portable case. These spectroscopes are sometimes made so small that they may be conveniently carried in the pocket.

Fig. 103.



Counteraction of Prisms.

Fig. 104.

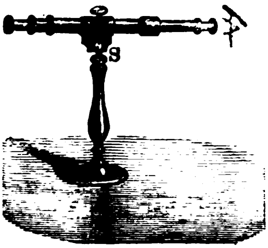


Straight Course of Ray.

## § 3. *Spectral Lines.*

**187. Newton's Spectrum imperfect.**—Newton used the light from a round hole in a window-shutter, so that his spectrum consisted of a series of overlapping images of the aperture, by which the colors were slightly mixed. In this way the deeper mysteries of the spectrum could not be disclosed; and for one hundred and twenty-seven years no progress was made in this branch of knowledge. But in 1802, Dr. Wollaston examined

Fig. 105.



Direct-Vision Spectroscope.

the spectrum formed by a narrow opening, and found that, instead of being so pure as was always supposed, it was crossed in various places by dark lines. The discovery, however, although it was the initial step of modern spectrum analysis, excited no interest at the time.

**188. Fraunhofer's Lines.**—The dark lines were afterward rediscovered, in 1814, by a German optician named Fraunhofer, who explored them so carefully that they have since been called after his name. He studied the spectrum, formed by a fine slit, with the telescope, and found that the lines were very numerous, that they varied in thickness and were distributed in unequal groups through the spectrum. He counted 590 from the red to the violet, and made a map of them (Fig. 106), designating the most important by the letters of the alphabet. Fraunhofer further found that the lines did not vary in sunlight, examined at different times; that the reflected light from the moon, or from Venus, gives the same distribution of them as the sun, while the spectra of the fixed stars differ from those of the sun, and from each other. From these considerations

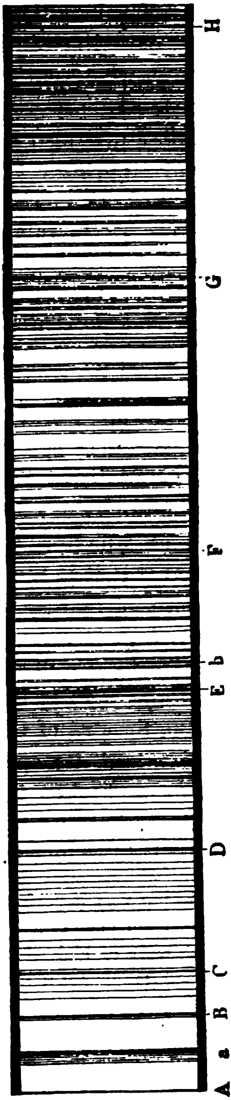


Fig. 106. Fraunhofer's Lines.

Fraunhofer drew the important conclusion that the cause of the dark lines in the solar spectrum exists in the sun, although what that cause could be seemed an impenetrable mystery.

**189. Dr. Draper's Investigations.**—The next most important step, after Fraunhofer, was taken by Dr. Draper, of New York. He was the first to use Fraunhofer's spectroscope in this country, more than thirty years ago. He modified it in 1842, in such a manner as to cast the fixed lines upon the sensitive surface of photographic plates, and published a map of the results, showing four great groups of these lines beyond the limit of the violet ray, and probably doubling the number of lines up to that time known. But, what is more important, he passed to the examination of spectra formed by incandescent terrestrial bodies, and discovered a principle which is fundamental in the philosophy of the subject. He determined the temperature at which a solid body begins to give off light, showed that it is the same for all solids; that, as the temperature increases, the colored rays are emitted in the order of their refrangibility, from red up to violet; and that the spectra of all incandescent solids are continuous, or without lines or breaks.[1]

**190. Spectra of Gaseous Bodies.** But when a solid body is volatilized, its spectrum is changed, becoming discontinuous, or broken up into separate lines; and these are not dark, but bright, and of various colors. If a little sodium is introduced into the gas-flame (Fig. 102), and the spectrum be then observed through the telescope, a bright-yellow line of light will appear, always in the same position; and, if a higher dispersive power is applied, this yellow line will be resolved into two, forming the double line which is the distinguishing spectral mark of sodium. If, now, potassium be submitted to the light, three lines appear, two red at one extremity of the spectrum, and a purple line at the other, all else being darkness. If electric currents are sent through pure hydrogen, oxygen, or nitrogen gas, each produces a spectrum of different lines, as shown in the colored frontispiece. The colors of the lines are as variable as the tints of the spectrum, and they vary in numbers through an immense range: while sodium gives but two lines, iron yields several hundreds.

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[1] As but very imperfect justice has been done to the work of Draper abroad, I am glad to notice the following admission from a recent and English work of high character: "It has been found that all solid and liquid substances act in the same way with regard to the increase of heat; they all begin to be visibly hot at the same temperature, and the spectrum is in every case a continuous one. This law was discovered by Draper (*Philosophical Magazine*, 1847). The only known exception to this law is glowing solid Erbia, whose spectrum exhibits bright lines."—(Roscoe's "Spectrum Analysis," third edition, p. 51.)

**191. What the Lines indicate.**—The spectral lines indicate first, chemical identity, and serve as tests of chemical substances. Each element gives a peculiar spectrum, distinguishable from all others in the number, color, breadth, and grouping of its lines. So distinct are they, that when a compound is vaporized all its elements are at once disclosed. If several substances are volatilized together, all the spectra can be identified. Most of the lines are mere films, like the finest spider's web, so that they really occupy but a very small portion of the spectrum space. In some cases, however, several of the bright lines of different bodies seem to coincide; but upon narrower scrutiny these have been generally found to show real though slight differences of refrangibility. Such coincidences as are still unsolved will probably disappear under higher instrumental power.

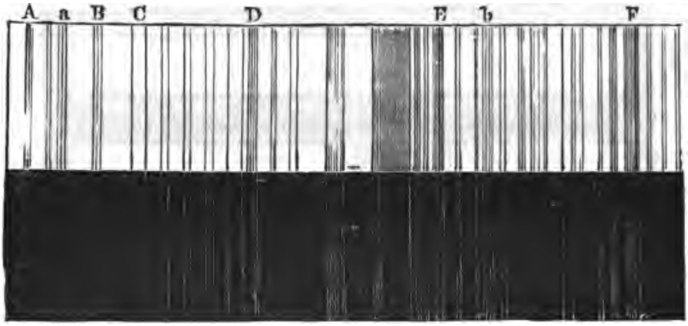
**192. Physical Indications.**—The spectral lines are also, to some extent, indices of physical states. With increasing temperature there is increasing brilliancy of the lines, and, with some metals, lines come out under intense heat that do not appear at lower degrees. Pressure or density also affects the spectrum. If the particles of a gas are forced together so as to approach the solid state, the spectrum-lines are widened into bands, so as to approach the continuous spectrum. The spectrum of hydrogen may be thus made continuous by great pressure. But this in no way interferes with the fixity of the bright lines, or their value as chemical tests.

### § 4. *Theory of Absorption.*

**193. What are the Spectrum Lines?**—The optical answer to this question is, that they are *images of the slit.* A slit of say the fiftieth of an inch would of course give on a screen a very fine white line, which would be simply an image of the aperture. Now, if that filmy ribbon of white light is passed through a prism, the spectrum formed will be a succession of colored lines into which the white line has been resolved, and the whole spectrum will be but a series of images of the slit, either continuous or broken. It is easy to recognize that the bright-colored lines are images, but it may be asked, what are the dark solar lines images of? Darkness is absence of light, and the dark lines of the spectrum simply indicate the absence of luminous rays. It is sometimes supposed that there are dark lines of gossamer delicacy in the sunlight, but this is a misconception. There are rays wanting in the sunlight, and in the spectrum these vacancies come out as lines of darkness. If the slit is changed to a cross, then, as the mark of sodium, we have a yellow cross, instead of a line, and black crosses in the spectrum of sunlight.

**194. Coincidence of Bright and Dark Lines.**—We thus reach the vital question of Spectrum Analysis, What has become of the missing rays of sunlight? and what is the relation between the dark solar lines and the bright lines produced by burning terrestrial substances? That there is some close relation was suspected by Fraunhofer, and maintained by others after him. The exact coincidence in position of the double dark line D of the solar spectrum and the double bright line of sodium attracted frequent attention, and it was thought it could not be accidental. This conclusion was at length reënforced by overwhelming evidence. The solution of the problem was given by Kirchhoff in 1859. In order to map the positions of the bright lines of various metals, he employed the dark lines of the solar spectrum as his guide. Upon placing one spectrum over the other, he was astonished to find that whole systems of lines in the two spectra were coincident in position and gradation. The coincidence of more than sixty bright lines of vaporized iron with the same number of dark solar lines, the brightest corresponding to the darkest, was shown as represented in Fig. 107, and Kirchhoff proved mathematically that the chances are more than 1,000,000,000,000,000,000 to 1 that this could not happen without some causal connection. Angström has since identified 470 bright iron lines with the dark solar lines, and it has been established that 75 lines of calcium, 57 of manganese, 33 of nickel, and 170 of titanium, exactly correspond in grouping, breadth, and degree of shade, with the same number of dark lines of the solar spectrum.

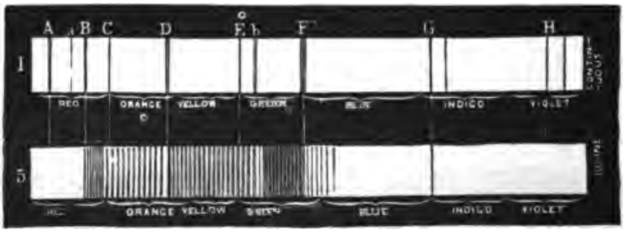
FIG. 107.



Coincidence of Bright Iron Lines with Dark Solar Lines.

**195. Absorption Lines.**—It was thus proved that both orders of lines belong together, and must have a common cause; but what is that cause? A step toward the answer was taken by producing the dark lines experimentally. When light is transmitted through certain vapors, and then passed through the prism, the spectra exhibit dark lines, which vary in the different cases. Fig. 108 represents the spectrum thus formed by the vapor of iodine. The dark lines, in the lunar band, show the rays that have been intercepted, or absorbed, on their passage through the vapor, and they are hence called lines of absorption.

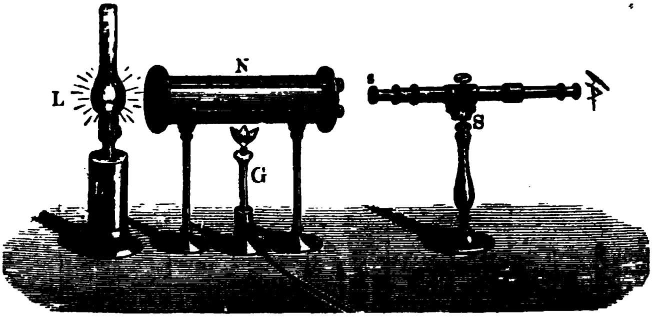
FIG. 108.



Absorption by Vapor of Iodine.

**196. What Lines are absorbed?**—Vapors absorb the kind of light that they emit, and let all other rays pass. Sodium-vapor gives out yellow light, and so it stops yellow light. This principle is so important that we must show how it may be proved. In Fig. 109 suppose the part *N G* removed, we shall then have the oil-lamp *L* giving light which produces a continuous spectrum, which is observed by the direct-vision spectroscope *S*, the light entering at the slit *s*. If now the glass tube *N* is interposed (which is filled with hydrogen, instead of air, to prevent combustion), and a little sodium is placed in it and heated by the gas-burner *G*, the tube becomes filled with sodium-vapor. Upon now observing the spectrum, it will be found that the red, orange, green, blue, and violet, have passed through unimpaired, while the yellow is absent, having been absorbed by the vapor. If vapors of lithium, strontium, or barium, are substituted, the colors that they emit when luminous are in like manner extinguished.

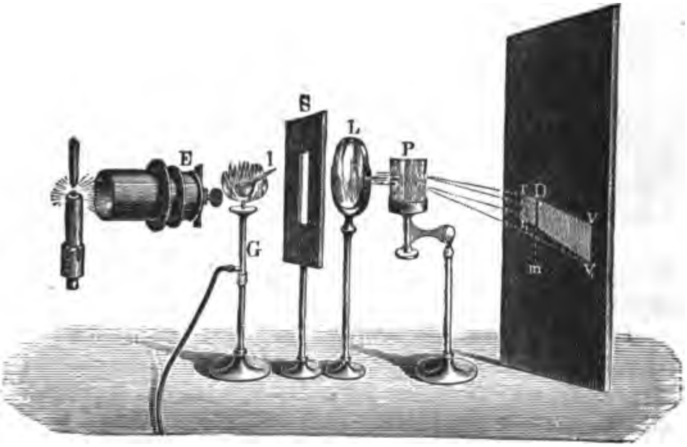
Fig. 109.



Absorption by Sodium Vapor.

**197. Reversal of the Lines.**—The change from bright to dark, or, as it is called, "the reversal of the spectrum," by absorption, may be more fully shown with the apparatus represented in Fig. 110. Suppose, again, the gas-burner *G* removed, and a little sodium placed upon the carbon of the electric-lamp. The rays emerging from the slit *E* pass through the lens *L*, and the prism *P*, and, falling upon the large screen, will give the yellow line of sodium, the position of which is marked at *m*. When the sodium has been all volatilized, its yellow line disappears, and there remains the continuous spectrum *r V*. Now restore the gas-burner *G*, into which there is inserted the spoon *l*, containing a bit of sodium, which soon tinges the flame yellow. The lesser screen *S*, which allows the rays to pass through its opening, shades the larger screen from the diffused light, and we have the dark line *D* exactly in the position it occupies in the solar spectrum. In the same way the spectral lines of potassium, lithium, strontium, and other elements, have been reversed by absorption, from which it is concluded that the dark solar lines are due to the same cause, or are reversed lines. It is, however, to be observed that these dark lines are only *relatively* dark. The sodium-vapor in the experiment continues to emit its bright rays, but the light intercepted is so much more brilliant than that emitted that the lines appear as dark spaces in contrast with the adjacent colors.

FIG. 110



Reversal of the Sodium Line.

**198. Theory of Absorption.**—Spectrum analysis is thus based theoretically upon a broad principle of physics. We have seen (89) that there is a fixed relation between the absorption and radiation of heat; that is, at a given temperature, as bodies absorb, so they radiate. We are more familiar with the principle in acoustics. Resonant bodies absorb only the vibrations they can give out. If we sing near the piano, the strings sometimes respond, but the response is always a note that has been sung. The note sung is not taken up by strings that vibrate differently. The string affected absorbs the vocal vibrations that strike them in one direction, and emits the same vibrations in all directions. So also with light. The rays to which an incandescent gas is transparent it cannot emit; only those which it stops, or absorbs, can it again give out. This is explained by the wave-hypothesis, on the principle that incandescent molecules can only absorb and emit undulations that are timed to their rates of vibration.

**199. Fraunhofer's Lines explained.**—The early and sagacious conjecture of Fraunhofer that the cause of the dark solar lines exists in the sun, and that they are lines of absorption, is thus verified; and, moreover, the explanation that is forced upon us gives a clew to the constitution of the sun itself. The solar metals must be in a volatile state, which implies an atmosphere surrounding the sun, and laden with metallic vapors. Below this there must be a liquid or solid nucleus of far greater heat, the main source of illumination, and that yields a continuous spectrum. This is called the *photosphere*, or light-giving stratum. As its light shines through the atmosphere above, the metallic vapors intercept the rays they can themselves emit, and thus fill the solar spectrum with dark lines, or lines of absorption (206, 207).

### § 5. *Spectroscopic Applications.*

**200. Delicacy of the Chemical Indications.**—Spectrum analysis affords a ready, certain, and delicate means of testing chemical bodies. There are various rare metals which resemble each other so closely, that they are distinguished with difficulty by the ordinary methods; but, however mixed together, or with other substances, when vaporized their characteristic spectral lines are detected at a glance. The amazing sensitiveness of the reactions has led to new results which would, a short time ago, have been regarded as incredible. The spectroscope will easily detect the one-eighteen-millionth of a grain of sodium, and it has shown that sodic chloride (common salt) is almost omnipresent.

It pervades the atmosphere in its dust, and we breathe it in the air we inhale. If we clap our hands, or shake our clothing, or jar the furniture, the dust set in motion contains sodium enough to affect the flame and give its reaction in the spectrum. Again, the six-millionth part of a grain of lithium is sufficient to reveal its beautiful red line, and it would be detected though mixed with ten thousand times its weight of other substances. It was formerly regarded as a very rare element, known to exist in only four minerals; now it is found almost everywhere—in the juices of plants, fruit, bread, tea, coffee, wine, tobacco, milk, and blood; also in meteoric stones, and the water of the Atlantic. Dr. Miller found that the stream of one spring poured out eight hundred pounds of lithic chloride every twenty-four hours.

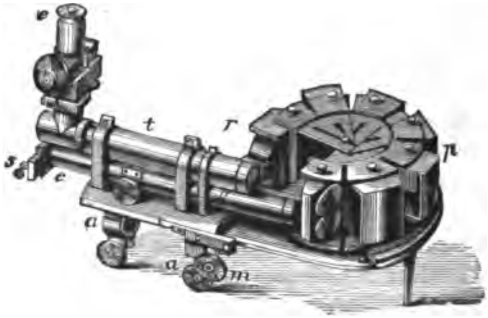
**201. New Elements.**—That elements which had hitherto eluded chemists should be caught by the spectrum tests was to be expected. Bunsen, in examining the spectra of alkalies from the ashes of a spring, at Durkheim, noticed some new lines, from which he inferred a new substance. He accordingly evaporated forty-four tons of the water, and from its residue extracted two hundred grains of what turned out to be the chloride of a new metal, which he called *cæsium*, from its bluish-gray spectral line. Three other metals, before unknown, and named Rubidium, Thallium, and Indium, from the colors of their lines, were subsequently found by the same means.

**202. The Spectroscope in Steel-Making.**—By what is called the "Bessemer process" cast-iron is changed directly into steel, by burning out its excess of carbon. A large amount of cast-iron—five tons at a time—is placed in a suitable vessel, called a "converter," where it is melted, and a copious stream of air is thrown into the bottom of the vessel by a powerful blowing apparatus. The atmospheric oxygen burns away the carbon and silicon from the molten cast-iron, and the heated gases issue in flame at the mouth of the converter. The operation lasts about twenty minutes, but it must be stopped at a certain point, and if it is done ten seconds too early or too late the whole mass is spoiled. The flame changes with the progress of the combustion, and, although a quick and experienced observer can judge very nearly when the time has come to stop the blast, yet the spectroscope shows the exact moment at which the carbon disappears, and the combustion must be arrested.

**203. Organic Indications.**—The investigations of the spectra of organic substances produced by burning, or by the absorptive action of their solutions, are already fruitful, and promise to be of great future importance. Solutions of blood, magenta, and various coloring-matters, are identified in extremely small proportions by the absorption-bands they produce; and, by a combination of the spectroscope with the microscope, blood-stains may be detected in which the spot contains only the thousandth of a grain of blood, and is fifty years old. The vintages of wine differ so considerably in successive years as to be at first readily distinguished, but as they grow old the discrimination becomes difficult and uncertain by ordinary means. A skillful English spectroscopist, Mr. Sorby, has, however, shown that, by this mode of testing, old vintages can be as well identified as recent ones. Again, this process has been made to throw light on physiological changes, such as the circulation, and the rate of diffusion in the animal system. Dr. Bence Jones injected salts of lithia under the skins of Guinea-pigs, and then, by the combustion of the tissues, at different times, the appearance of the red lithium-line showed the rate of diffusion of the substance. Three grains being thus injected, in four minutes it was found to have made its way into the bile and the aqueous humors of the eye, and in ten minutes traces of it were detected in the crystalline lens.

**204. The Tele-Spectroscope.**—But by far the most impressive of all the applications of spectrum analysis is to the heavenly bodies. An instrument adapted for this purpose, and attached to the telescope, is called the tele-spectroscope. Fig. 111 represents the one employed by Prof. C. A. Young, of Dartmouth College, in his solar researches: *a a* are clamping-rings, which slide upon a strong metal rod firmly fastened to the telescope, and which brings the slit *s* of the instrument exactly in the focus of the object-glass, where the image of the celestial object is formed. The light passes through the collimator *c* (about an inch in diameter and ten inches long) and traverses the train of six prisms *p* near their bases. It is then twice reflected by a rectangular prism *r*, and sent back through the upper portions of the same prisms, by which the effect is doubled. After this twelvefold dispersion the rays pass through the lesser telescope *t*, and, being again reflected for convenience of observation, are received by the eye at *e*. The tangent screw *m* serves to adjust the position of the prisms.

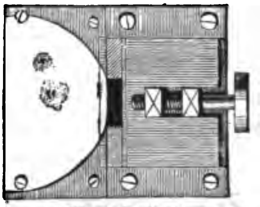
FIG. 111.



Spectroscope, with Train of Prisms.

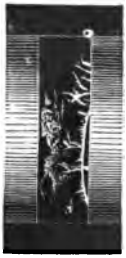
**205. Viewing a Solar Prominence.**—Fig. 112 represents the slit-plate of the spectroscope, of its actual size, the oblong black square being the slit widely opened by the screw. This is brought to the edge or limit of the sun's image represented by the white circular space. A sunspot is shown near by, and these are often accompanied by prominences. The slit is shown in Fig. 113 on an enlarged scale. If the instrument is so adjusted as to bring the Fraunhofer line *C* into the centre of the field of view, then on looking into the eye-piece an effect resembling that in the figure may be seen. Prof. Young says: "The red portion of the spectrum will stretch athwart the field of vision like a scarlet ribbon with a darkish band across it, and in that band will appear the prominences like scarlet clouds; so like our own terrestrial clouds, indeed, in form and texture, that the resemblance is quite startling; one might almost think he was looking out through a partly-opened door, upon a sunset sky, except that there is no variety or contrast of color; all the cloud-tints are of the same pure sunset hue."

FIG. 112.



Opened Slit of the Spectroscope.

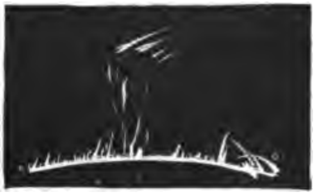
FIG. 113.



Spectroscopic Aspect of a Prominence.

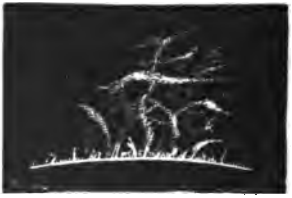
**206. The Solar Envelope.**—To the eye of science the sun is a very different object from that which appears to common observation. The light-giving portion, which seems to form his true surface, and is called the photosphere, while it incloses the chief mass of the sun, is estimated to indicate but half its real diameter, and but one-seventh of its volume. It is surrounded by a vast, irregular, variable atmosphere, or envelope, in the most violent agitation, and sending out eruptive masses at a rate of motion and on a scale of magnitude that are almost inconceivable. This envelope consists of different parts, which, though they can hardly be regarded as stratified, yet conform to a general order of position. Lying upon the photosphere is what appears like a layer of scarlet fire, called the chromosphere, which is five or six thousand miles in thickness. Its appearance, according to Young, "is as if countless jets of heated gases were issuing through the vents and spiracles over the whole surface, thus clothing it with flame, which heaves and tosses like the blaze of a conflagration." At different points are thrown up enormous masses of gaseous matter to various elevations, which are called prominences, or protuberances. Many hundreds of them have been observed and measured, and the most of them vary from fifteen to seventy-five thousand miles in height. Numerous instances are recorded of their reaching an elevation of one hundred thousand miles, and Prof. Young saw one over two hundred thousand miles high. Their motions often have a velocity of one hundred miles per second, and sometimes of double that rate. "Their form and appearance frequently change with great rapidity, so that the motion can almost be seen with the eye— an interval of fifteen or twenty minutes being often sufficient to transform, quite beyond recognition, a mass of these flames fifty thousand miles high, and sometimes embracing the whole period of their complete development or disappearance. Sometimes they consist of pointed rays, diverging in all directions, like hedgehog-spines. Sometimes they look like flames; sometimes like sheaves

FIG. 114.



Vertical Eruption.—100,000 miles to the inch.

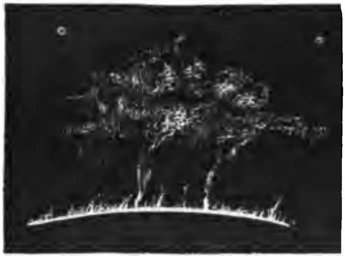
FIG. 115.



Filamentary Prominence.

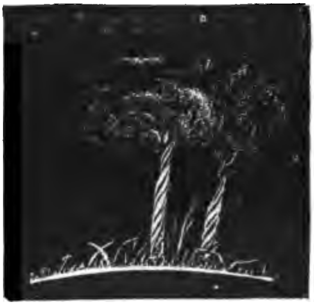
of grain; sometimes like whirling water-spouts, capped with a great cloud; occasionally they present most exactly the appearance of jets of liquid fire, rising and falling in graceful parabolas; frequently they carry on their edges spirals like the volutes of an Ionic column; and continually they detach filaments which rise to a great elevation, gradually expanding and growing fainter as they ascend, until the eye loses them."—Young.

Fig. 116.



Stemmed Prominence.

Fig. 117.



Cyclonic Prominence.

**207. Elements in the Sun.**—The principal constituent of the chromosphere is hydrogen gas, which is always present, as shown by the length and brilliancy of its spectral lines. The prominences are regarded as local accumulations of the chromosphere, which seem to force their way up from the interior of the sun with great violence, in the form of monster irruptions, which consist mainly of incandescent hydrogen. There is no evidence of oxygen, nitrogen, or carbon, in the sun. Besides hydrogen, the spectrum reveals the following solar elements, as lately stated by Professor Roscoe:

1. Sodium.
2. Calcium.
3. Barium.
4. Magnesium.
5. Iron.
6. Chromium.
7. Nickel.
8. Copper.
9. Zinc.
10. Strontium.
11. Cadmium.
12. Cobalt.
13. Rubidium.
14. Manganese.
15. Aluminium.
16. Titanium.

These elements exist in a condition of ignited luminous vapor, most abundant in the lower parts of the chromosphere, but many of them are thrown up to great heights in the prominences. They, no doubt, undergo condensation by cooling, and pour back upon the liquid photosphere dense sheets of metallic rain. Prof. Young states that sulphur is probably present in the chromosphere, and traces of other elements are reported. There are also solar lines which correspond to no known terrestrial substance.

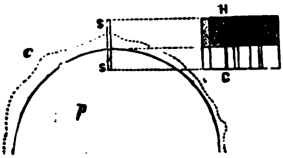
**208. Elements in the Stars.**—Light is the same throughout the visible universe; its nature is not changed by the distances through which it travels. In the case of the stars we have to deal with radiations, greatly weakened in intensity, yet, such is now the wonderful delicacy of the tests, that it has been lately proved that heat-rays are associated with the stellar light, and, as we have already seen, the chemical rays, also. When the light of the stars is studied by the spectroscope, it testifies, still further, to the physical unity of the universe, by showing that the same chemical elements which exist upon earth, and in the sun, are found, also, in these distant bodies. In the spectrum of one star, Aldebaran, the lines of nine elements have been identified, viz., hydrogen, sodium, magnesium, calcium, iron, antimony, mercury, bismuth, and tellurium—the two latter not having been found in the sun. Other stars give different spectra; many hundreds have been observed, and hydrogen discovered in all except two. The stellar lines are both dark and bright, the former indicating a white-hot nucleus, sending its light through absorbing vapors, and the latter indicating a chromosphere. Spectrum analysis thus adds its powerful evidence to that already existing, to show that the stars are suns, similar in constitution to our own.

**209. A Star in Conflagration.**—In May, 1866, a star in the constellation of the "Northern Crown," of the tenth magnitude, and so small as to be hardly known, was observed to suddenly blaze out, and attain an apparent magnitude equal to that of the largest stars. Examined by the spectroscope it was found that, in addition to the usual dark lines, there were the bright lines of hydrogen, remarkably clear. The star, however, soon began to fade, and the bright lines to dwindle, and after the lapse of twelve days, when it had fallen to the eighth magnitude, these lines had totally disappeared. It seemed like the outburst of prominences upon our own sun, though on a far more stupendous scale.

**210. Marvelous Delicacy of the Investigation.**—In the case of the sun, the spectroscopist has to deal with light of overpowering brilliancy, his meridian rays being many times more intense than can be produced by any artificial means; but the light of the stars is at the opposite extreme. We shall appreciate the difficulty of these observations by remembering that the light of a star emanates from a mere point—that is, it has no sensible magnitude, and has to be kept steadily upon a slit only the $\frac{1}{300}$ part of an inch in breadth, and which is constantly altering its position with the motion of the earth. Moreover, this faint line of light has to be still further weakened by being spread out into a band. The air, besides, is so unsteady as to cause flickering, and confusion of the spectrum. Yet over all these embarrassments skill and patience have proved victorious. Roscoe says the spectrum of the star Sirius has been photographed by Huggins. The intensity of the light of this star is, according to the best measurements, the $\frac{1}{5,000,000,000}$ part of that of the sun; and, although probably not less in size than sixty of our suns, it is estimated to be at the enormous distance of more than 130,000,000,000,000 miles; and yet even this immense distance does not prevent us registering the chemical intensity of the rays which left Sirius twenty-one years ago (MILLER).

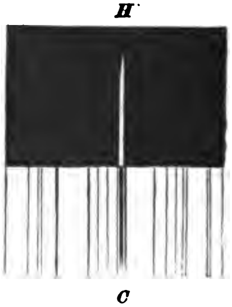
**211. The Double Solar Spectrum.**—Another remarkable result remains to be noticed, the spectroscopic proof of the motions of celestial masses; and to explain this we must refer again to the sun. As from his photosphere we get dark lines, and from his chromosphere bright ones, how are they related to each other? The lines from the same elements having the same positions, if the bright and dark spectra are brought together they should be continuous, and such is the fact. If the spectroscope be placed *radially* (Fig. 118), so that the slit *s s* covers the photosphere *p* and the chromosphere *c*, a double spectrum will be seen, and the dark lines will coincide with the bright lines. In Fig. 119 the dark Fraunhofer line *C* is continuous with the scarlet hydrogen-line, and the same continuity is observed with the lines of other elements.

FIG. 118.



The Two Solar Spectra.

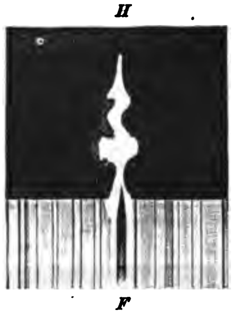
FIG. 119.



The Spectrum of the Sun's Disk below, and that of the Chromosphere above, near the C-line.

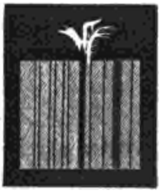
**212. Variations of the Bright Solar Lines.**—It has been stated that the changes in the aspects of the lines may indicate physical alterations in the substances producing them, the hydrogen-lines, for example, being widened when the gas is under pressure. The bright solar hydrogen-line *H* (Fig. 119) is generally more slender than the dark line *C*, which is explained by the greater rarity of the hydrogen in the higher region of the chromosphere. At the base, however, it is seen to be widened, an effect due to the pressure of the superincumbent mass. But it is also observed that the bright hydrogen-lines are often bent, widened, twisted, and displaced, in a very remarkable way. Fig. 120 represents *F*, as pictured by Lockyer, strongly bulged and contorted; and Fig. 121 shows it as affected by a solar cyclone. These alterations of the positions of lines, in the spectrum, are simply changes of refrangibility, and, as the corresponding dark lines suffer no disturbance, at the same time we have to seek the cause of the altered refrangibility in some change of the hydrogen-mass above. An illustration from sound will help us to understand the cause of this. When in a railway-train we listen to the whistle of a rapidly-approaching engine, as it passes, the pitch of the sound falls. This is because, with the advance of the engine, the rate of air-vibrations striking upon the ear is increased. In the same way, if a luminous body is very rapidly approaching the eye, the ethereal waves that enter it are increased in number, and, as color depends upon their rate, the pitch of color, so to speak, will be altered. In the spectrum the effect would be to change the refrangibility of the rays, and consequently the position of the lines. With the swift approach of the body the more rapid wave-beats would displace the lines toward the violet, while the recession of the body would shift them toward the red. From this cause of variation in the lines, it becomes possible to trace the direction of gas-streams, cyclones, and the course of eruptive masses, and to account for the otherwise inexplicable mutations of the bright solar lines.

FIG. 120.



Changes in the *F*-line.

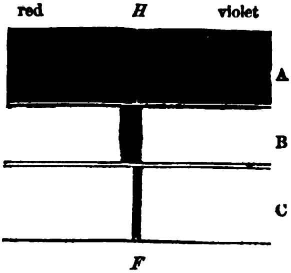
FIG. 121.



The *F*-line in a Solar Cyclone.

**213. Motions of the Stars.**—Perhaps the most splendid triumph of spectrum analysis is the application of this principle to the determinations of the motions of the stars. Hitherto observations have been limited to movements across the field of vision. Spectrum analysis proves the approach and retreat of the stars by the displacement of the hydrogen-lines. Mr. Huggins first established this by a series of observations upon Sirius of the most consummate delicacy. A powerful spectroscope being applied, a slight displacement of *H* toward the red was discovered and verified by numerous observations. Fig. 122 shows the position of this line in Sirius, as compared with its other determined positions. The normal position is obtained by sealing up pure hydrogen in a vacuum-tube, free from pressure, and passing through it a stream of electric sparks. It will be seen that the *F*-line of Sirius is started toward the red, as compared with both its normal and its solar positions. This displacement exactly measured corresponds to a receding motion of the star of twenty-nine miles per second. Later observations by Mr. Huggins, with instruments of still higher power, confirm and extend these results. Arcturus is shown to be approaching us at the rate of fifty-five miles per second, and the motions of various other stars have been established.

Fig. 122.



*A*, Hydrogen-line in Vacuum-tube; *B*, *F*-line in the Spectrum of Sirius; *C*, *F*-line in Solar Spectrum.

Only a meagre outline of spectrum analysis has here been given, and it can convey but an imperfect idea of the extent, precision, and surprising harmony, of the knowledge that has so quickly arisen upon this interesting subject. Those who care to pursue the subject further, are referred to the works of Schellen, Roscoe, and Lockyer.

# PART II.

# CHEMICAL PRINCIPLES.

## CHAPTER VIII.

### GENERAL CHARACTER OF CHEMICAL ACTION.

**214.** FROM the study of those molecular forces which determine the forms of matter, and variously influence chemical phenomena, we now pass to the consideration of chemical changes themselves. There are, however, certain elementary facts and principles of the subject, leading to important theoretical views, which it is necessary to consider before stating the peculiar language of chemistry, or entering upon the detailed description of chemical substances.

**215. The Chemical Force.**—Affinity, chemism, or chemical force, are names given to that power in Nature which produces transformations of matter by altering its composition. It acts only at insensible distances, or when different substances are brought into the closest relation with each other; but its effects are conspicuous, numberless, and of the highest importance. It is an inherent and universal energy of the natural world, from which no form of matter is exempt, and causes incessant and innumerable changes everywhere, around and within us. In the production of all its effects, the chemical force conforms to exact and inflexible laws, forming a science equally remarkable for the beauty of its principles, the depth of its philosophy, and the practical value of its applications.

**216. Elements and Compounds.**—Chemical force comes into play only between different *kinds* of matter. If there were but one kind of matter in the universe, there might be physics, but no chemistry; this science, therefore, deals with *composition*, and implies elements and compounds. As the letters of its alphabet make up all the words, sentences, and books of a language, so a small number of chemical elements compose all the objects of Nature, and many thousand artificial compounds made by chemical experiment. All chemical changes consist in producing, altering, or destroying compounds. The separation of compound bodies into simpler ones is called *decomposition;* the process of separation, *analysis.* A highly-complex body, like flour, may be first separated into simpler substances, as gluten, starch, oil, and water, and this would be *proximate* analysis; these bodies may be again separated into their final elements, which is *ultimate* analysis. Synthesis is the reverse process, by which simpler bodies are built up into those of greater complexity. *Qualitative* analysis determines of what elements a compound consists; *quantitative* analysis ascertains their *proportions.*

**217. Characteristic Effects of Chemical Force.**—It has been stated that the physical forces alter only the forms of bodies, but do not affect their nature. Chemism goes deeper, destroying the distinctive qualities of substances and producing new ones. Newness of properties in the bodies formed is a consequence of all chemical action. It may convert two solids into a liquid, two liquids into a solid, or even two gases into a solid. Thus, when black charcoal and yellow sulphur combine, the compound formed is colorless as water, and highly volatile. Sulphur and quicksilver unite to form the bright-red vermilion. Nitrogen and oxygen are neutral and tasteless, separate or mixed; yet one of their compounds, laughing-gas, is sweet, producing delirium when breathed; and another, nitric acid, is an intensely sour corrosive poison. Carbon and hydrogen are odorless, yet they combine to produce our choicest perfumes. Mild and scentless hydrogen and nitrogen form the pungent ammonia; while suffocating and poisonous chlorine, united with a brilliant metal, gives rise to common salt. There is, however, a gradation in these effects. Substances resembling each other only lose their properties partially; and the wider their differences, the more complete is the transformation. If the elements are very similar, the compound will show its parentage, as, for example, in the union of metals forming an alloy; if quite unlike, all traces of its derivation will be lost.

**218. Gradations in Chemical Attraction.**—When two bodies unite to form a new substance, the chemical force may not be satisfied, and the compound may again unite with other substances, forming bodies still more complex. But in such cases the combining power is progressively weakened. Hence highly-complex bodies are generally less stable than simpler ones. Thus, for example, crystallized alum, a complex substance, may be easily decomposed into the simpler compounds, water and burnt alum. The latter, again, may be separated into potassic sulphate, and aluminic sulphate. But it requires greatly-increased power to decompose these into sulphur, potassium, oxygen, and aluminium; while no power hitherto applied has been sufficient to decompose these substances, and they are hence classed as elements. So far, only sixty-three of these simplest forms of matter have been brought to light, most material objects being, therefore, compounds. A list of the elements is given in the Appendix.

**219. Conditions of Chemical Action.**—These are many and various. Such is the range of intensities manifested by chemical substances, that, while a mere touch, or a beam of light falling upon a body, will sometimes destroy its composition, in other cases decomposition can only be brought about by the intense and prolonged application of force.

**220. Influence of Cohesion.**—As chemical combination involves a total change in the arrangement of the internal parts of bodies, it is clear that cohesion, which tends to hold them in certain fixed positions, must be opposed to chemical union; and, on the contrary, any thing which gives mobility to the particles of different substances and enables them to approach within shorter distances of each other, must tend to promote it. Hence it is only in few instances that solids combine directly. Their combinations are facilitated by pulverization and grinding in mortars, or by the aid of heat or other forces. Usually, one at least of the combining bodies must be in the liquid or the gaseous state before chemical action can take place.

**221. Influence of Heat and Light.**—Heat is a potent agent of chemical change from its control over the forms of matter; and so constantly is it used in the laboratory that the chemist used to be called the "Philosopher by fire." Sometimes it brings bodies into conditions favorable for union, and then it may set up repulsive actions by which combination is overcome. Sulphur, in the melted state, will not combine with carbon; it must be converted into vapor, and the carbon heated to redness, before they can be made to unite. The chemical action of light has been already considered.

**222. Influence of Electricity.**—Electricity also determines the combination of many substances, especially gases, acting perhaps indirectly by elevation of temperature. By passing through the mixture an electric spark, the union of oxygen with hydrogen, and of chlorine with hydrogen, is instantaneously brought about. The voltaic current also, as has been before pointed out (141, 142), is one of the most powerful agents of decomposition possessed by the chemist.

**223. Chemical Induction.**—A body in the act of chemical combination or decomposition often induces the same kind of activity in another body, producing changes in them by a kind of induction. Thus pure copper does not dissolve in dilute sulphuric acid, while zinc does. But when one part of copper is alloyed with three times its weight of zinc, both metals pass into solution. Again, the compounds of several metals with oxygen, perfectly stable by themselves at ordinary temperatures, may be decomposed with almost explosive violence by being brought into contact with a very unstable compound of hydrogen and oxygen—hydrogen dioxide—both compounds being decomposed together.

**224. The Nascent State.**—The moment in which substances are liberated from union with each other is called the *nascent* (forming) state, and, at this time, they often enter into combinations which could not be formed under other circumstances. Nitrogen and hydrogen gases, if mingled, do not unite; but when set free from their combinations they readily recombine, at the moment of chemical change, to form ammonia.

**225. Catalysis.**—The chemical union of bodies is often effected or aided by the bare presence of a substance which does not itself undergo any alteration during the process. Thus the presence of finely-divided platinum brings about the combination of oxygen and hydrogen gases at ordinary temperatures, which would otherwise take place only at red heat. This is apparently due to the power of finely-divided and porous bodies to condense gases on their surface, whereby the atoms of the combining bodies are brought into closer contact. This form of chemical induction is termed *catalysis*, or contact action.

**226. Intensities of Chemical Action.**—Chemical force acts through an infinite range of intensity. Sometimes the changes proceed slowly, as in rocks and soils; sometimes rapidly, as in growth, decay, or putrefaction; and sometimes with great violence, as in combustions and explosions. Our life depends upon that quiet rate of chemical change which takes place in breathing or respiration.

But the same force may act with such terrific power that a few ounces of nitro-glycerine exploded upon the surface of a rock will shatter it to fragments. That such forces may be dealt with, and such operations controlled, is because they are governed by inflexible laws.

**227. The Mathematical Basis of Chemistry.**—One of the greatest discoveries of modern times is the truth that Nature works with the same exactness on the small scale as on the large. It is the glory of Newton to have proved that the material objects of the universe attract each other according to a definite mathematical law by which all the celestial and terrestrial motions of bodies are regulated. It has been established by chemists that the minutest particles of matter, in their actions and reactions, obey a corresponding law, and that every chemical compound has a mathematical constitution as fixed as that of the solar system itself. The stones and soil beneath our feet, and the ponderous mountains, are not mere confused masses of matter; they are pervaded throughout their innermost constitution by the harmony of numbers. The fuel we burn wastes away before us, dissolves in air, and passes beyond the reach of sight; but the invisible changes among the unseen particles are definite, exact, and harmonious. And so it is with all chemical mutations. When instruments of weighing had attained sufficient perfection, it was found that, however often matter might change its form, nothing was either gained or lost—that its quantity remained the same; and it was soon found that the constituents of chemical compounds always combine in the same proportions.

**228. The Law of Definite Proportions.**—When the composition of a sample of pure water, common salt, lime, cr any other substance, is once accurately determined, the knowledge applies to all these substances—their elements enter into them in constant and invariable proportions. Pure water consists of 1 part by weight of hydrogen, and 8 parts by weight of oxygen; common salt of 35.5 parts of chlorine to 23 of sodium. This principle is known as the law of definite proportions, and its consequence is that every chemical element has a numerical property by which it is governed when entering into combination. These quantities are known as combining numbers. The principle holds, moreover, in the union of compounds with each other, as well as with elements; the combining number of a compound being determined by adding together the combining numbers of its constituents.

**229. The Law of Multiple Proportions.**—The old idea, that chemical combination was indefinite, long held its ground against the gradually accumulating proofs that all combination is definite and constant. But, when this principle was established, it soon led to the discovery of another, known as that of the multiple proportions of combination. It was found that two elements may combine so as to produce several different substances, and that the proportions of one or both elements will be variable in the different compounds. But these variations are in simple numerical proportions, each part being exactly doubled or tripled in its quantity. Hence, when combinations occur in more proportions than one, the larger quantities are multiples of the smaller by a *whole number*. This principle is formulated as the law of multiple proportions, and is illustrated by the following example of the ratios in which carbon and oxygen unite:

| | Carbon. | | Oxygen. |
|---|---|---|---|
| Carbonic monoxide | 12 | : | 16 |
| Carbonic dioxide | 12 | . | 32 |

The law is still more marked in the case of a series of compounds of nitrogen and oxygen:

| | Nitrogen. | | Oxygen. |
|---|---|---|---|
| Nitric mon-oxide | 14 | : | 8 |
| Nitric dioxide | 14 | : | 16 |
| Nitric trioxide | 14 | : | 24 |
| Nitric tetraoxide | 14 | : | 32 |
| Nitric pentoxide | 14 | : | 40 |

**230. Equivalent Proportions.**—It results, from the foregoing, that the proportions, or multiples of them, in which two bodies combine with a third, are those in which they combine with each other. For example, 71 parts of chlorine unite with 32 parts of sulphur, and with 56 parts of iron; but 32 to 56 is the ratio in which sulphur combines with iron. These relative numbers have been called equivalent proportions, or equivalents; but this idea has recently undergone very important modifications, and an enlarged and more accurate conception of it has become the basis of the new system of theoretical chemistry now to be considered.

## CHAPTER IX.

### THEORETICAL CHEMISTRY.

### § 1. *Theory of Atoms and Molecules.*

**231. The Old Atomic Theory.**—It was an ancient speculation that all matter is made up of atoms, or exceedingly minute particles, which are endowed with powers and virtues that explain all the properties of things, and the effects they produce. It was warmly disputed whether these particles are capable of being divided and subdivided to infinity; but there were no data for determining this question, and the vague notion of the atomic constitution of matter remained for thousands of years nothing more than an ingenious guess.

**232. Dr. Dalton revives it.**—But, when science had experimentally proved that there are definite numerical relations among the minutest parts of matter, this old problem was placed in a new light. The idea of the definite proportions of chemical combination, at first strongly resisted, was established near the close of the last century. It was soon extended by Dr. Dalton, of Manchester, England, who discovered the law of multiple proportions; and, to explain it, he went back to the old Greek conception of atoms. He assumed—1. That all matter consists of ultimate and unchangeable particles or atoms; 2. That atoms of the same element have a uniform weight, but that in different elements they have different weights; 3. That the combining numbers of chemistry represent these relative weights; and, 4. That between these different atoms there are attractions, which unite them by juxtaposition in the formation of chemical compounds. Dr. Dalton maintained that, if these ideas are accepted, the constancy of chemical characters and the definite and multiple proportions of combination follow as necessary consequences. This theory has been of great service in the modern development of the science; but it has been gradually extended and altered, until it now assumes a quite different form from that which it had at first.

**233. The Molecule in Physics.**—The extension of the atomic theory has consisted in the far greater prominence and distinctness recently given to the conception of the molecule; a conception which has become fundamental, both in physics and chemistry. We have seen (26, 27, 75) that the physicist regards all matter as made up of separated units, with intervening spaces that allow a varied freedom of movement; and that upon this idea is based the molecular dynamics of the three states of matter. To the physicist, therefore, molecules are not abstractions, but actual things, having definite magnitudes (274), and he defines them as *the smallest particles of matter which move as units from state to state, under the operation of physical forces.*

**234. The Molecule in Chemistry.**—To the chemist the molecule has also become no less a real thing, but he views it in a different aspect. The physicist takes it as a unit, and asks no questions as to what it is made of; but this is exactly the question of the chemist. He is to find out whether the molecule be simple or compound, what kind or kinds of matter it contains, and what is its constitution. The physicist, for example, grinds a bit of sugar down to the finest particles of microscopic dust not the ten-thousandth of an inch in diameter, but each particle still presents all the properties of the lump, and he is very far from having yet arrived at the molecule. He now puts it into water and it disappears, changing to the liquid state. The visible particle may be thus divided into perhaps millions of molecules, and when the water is evaporated the sugar returns to the solid state, with all its properties unchanged. Again, a bit of common salt, if sufficiently heated, passes into the state of vapor, its molecules being driven widely asunder; but when condensed we again have the substance, with its characters unaltered. The chemist now puts the sugar to a test from his point of view. He heats it, or acts upon it by a strong chemical agent, and finds that it contains three kinds of matter, carbon, oxygen, and hydrogen. The sugar is destroyed, and the three new substances produced from it exactly equal it in weight. The sugar-molecule, he says, is therefore not chemically a unit, but a compound. He proves that the soda-molecule is a compound also, consisting of two different kinds of matter, oxygen and sodium. To the chemist, therefore, the molecule is not an ultimate unit, but a group of units of a still lower order; and he defines the molecule to be *the smallest particle of a substance which is capable of existing in a separate condition, and in which its properties are preserved.*

**235. The Atom in Chemistry.**—The ultimate unit of the chemist is the *atom.* Molecules and atoms have hitherto been confounded together; but in the present state of chemical science they represent totally different things. A molecule is a group of atoms united by chemism, and capable of existing by itself; an atom is the smallest quantity of a substance that can enter into combination to produce the molecule. Atoms are indestructible, molecules susceptible of endless change. All chemical reactions are therefore operations on molecules which are expressed in terms of the atoms that compose them. A group of the same kind of atoms forms an elemental molecule; a group of different kinds of atoms forms a compound molecule. The breaking up of a molecule into its component atoms is *analysis;* the binding together of atoms to form molecules is *synthesis;* and the interchange of atoms between different molecules is known as *metathesis.*

**236. Symbols of Atoms.**—The chemical elements are represented by symbols which are the first letters of their names, and where different elements have the same initial letter a small letter is added, or the first letter of the Latin synonyms. Thus, N stands for nitrogen, B for boron, Br for bromine, and Fe for iron (*ferrum*).

But the letter does not merely represent the substance; it stands for a certain quantity of it, the smallest that can enter into combination—the atom. H not only symbolizes hydrogen, but one atom of it, the weight of which is taken as 1. C stands for the carbon-atom, which has a combining weight of 12; and O for the oxygen-atom, weighing 16. These are the proportional numbers of combination, and are also called atomic numbers. The molecules will, therefore, be represented by writing together the symbols of the atoms of which they consist, thus: H, hydrogen, and Cl, chlorine, combine to form hydric chloride, HCl, the symbol of the molecule. The single letter always signifies one atom, but, if several atoms are to be indicated, small Arabic numerals are employed, thus: $S_6$ means six atoms of sulphur, $P^4$ four atoms of phosphorus; $H_2O$ represents the molecule of water, and $CO_2$ the molecule of carbonic dioxide. To represent several molecules a large figure is prefixed, thus: $2H_2O$ indicates two molecules of water, $4CO_2$ four molecules of carbonic dioxide, and $10\,(C_2H_6O)$ ten molecules of alcohol. By adding together the atomic weights of the elements, in a molecule, we get the molecular weight. Thus for water, $H_2O$, it is 18; for carbonic dioxide, $CO_2$, it is 44. The symbols and atomic numbers of all the elements are given in a table in the Appendix.

## § 2. *Progress of Chemical Theory.*

**237. Earlier Views.**—The progress of chemistry has consisted in the advance of theory, that is, in an ever-widening view of facts, and a deeper insight into their relations. The most ancient theories of material things referred them to some essential principle, as air, water, or fire; and then, later, these ideas were combined. The objects of Nature were held to be formed of various commixtures of four elements, fire, air, earth, and water; and for many centuries the properties and changes of all substances, animate and inanimate, were explained on this hypothesis. In the seventeenth and eighteenth centuries, alchemy, the old mystical pursuit of the art of gold-making, gradually grew into a rough science of experiment by which much became known of the qualities of different kinds of matter. For a hundred years the explanation of chemical changes was given by the theory of *phlogiston.* This was held to be a kind of subtile matter, present in all combustible bodies, and absent in all incombustible bodies, and which caused combustion-changes by its escape. The doctrine is now regarded as a very crude one, but it contained truth, and was of great service, in its time. A chemical belief that the discoverer of oxygen, Dr. Priestley, held to the day of his death, could certainly not have been an absurdity. Prof. Cooke has the following excellent remarks on this early theory: "That it was not absurd a single consideration will show. Translate the word *phlogiston*, *energy*, and in Stahl's work on chemistry and physics, of 1731, put *energy* where he wrote *phlogiston*, and you will find there the germs of our great modern doctrine of conservation of energy—one of the noblest products of human thought. It was not a mere fanciful speculation which ruled the scientific thought of Europe for a century and a half. It was a really grand generalization; but the generalization was given to the world clothed in such a material garb that it has required two centuries to unwrap the truth."

**238. The Binary Theory; Dualism.**—With the abandonment of phlogiston as a ruling principle of chemical change the conception of affinity came forward, and chemical effects began to be referred to inherent attractions among different kinds of matter. At the epoch of Lavoisier, affinity was thought of simply as a coupling force. Combination and decomposition were supposed to take place directly among bodies in pairs; elements uniting with elements to form binary compounds, and these uniting again by twos to form double binary or ternary compounds; and, when these were made to act on each other, the reaction was represented as a double decomposition. This was known as the dual theory, and was commended for its simplicity and strongly confirmed both by the beautiful nomenclature which was adapted to it, and by the atomic theory which followed soon after. Powerful aid was also subsequently lent to it by electro-chemistry. Compounds were resolved into pairs by galvanic decomposition, and their elements were supposed to be in opposite electrical states, and to be united by polar forces. In this system the controlling idea was *the properties of the elements*, which were supposed to give character to compounds, and the main question was, What bodies does a substance yield upon analysis? The properties of compounds were referred to the presence of predominating constituents, and hence oxygen was named as the *acid-former*, and hydrogen as the *water-former*. The question as to how the constituents of a compound were grouped was hardly raised; yet it now turns out to be a question of very great importance.

**239. Unitary or Substitution Theory.**—But, as chemical changes were more closely studied, it was increasingly felt that dualism, or mere splitting and pairing, gave a totally insufficient account of them. There was a truth in this idea, but it was not the whole truth. The conception of atomic groupings in a molecule, and of the molecule as having a unitary constitution, gradually rose into clearness. It was found that the changes that take place among chemical compounds were rather of the nature of replacements and substitutions, which left the structure of the molecule intact. The constitution of the molecule, therefore, became the main object of investigation. It was found, moreover, that the most opposite elements could replace each other in a group without altering its chemical character. Chlorine, a powerful electro-negative element, could be substituted for hydrogen, a strong electro-positive element, in a compound, without changing its characteristic properties. Chemical compounds, instead of being likened to magnets, with a twofold attraction of opposite poles, were now likened rather to crystals whose angles and edges may be replaced by new matter, the form being maintained.

**240. Theory of Chemical Types.**—The unitary theory attained fuller expression in the theory of types, in which molecular structure first became a basis of classification. Most chemical changes were viewed as replacements, which conformed to a few general modes. As the stones of an edifice may be successively exchanged, leaving the style of architecture undisturbed, so atoms may replace atoms, leaving the types of molecular structure unaltered. This important idea was at the basis of the theory. Gerhardt proposed four such general types or patterns, taking hydrogen, hydric chloride, water, and ammonia, as representative bodies, and classing with them all substances which exhibit analogous reactions. But the exceptional compounds were so numerous that the system was held to be inadequate for classification, though invaluable as a transition-step to something broader and more satisfactory.

## § 3. *Theory of Atomicity and Quantivalence.*

**241. Variable Combining Capacity.**—The general theory of chemistry now adopted is the outgrowth of preceding theories, and embodies the truths they have severally attained. But it adds an important principle which throws further light upon chemical operations, and serves to organize into a better system the later facts and ideas of the science. The notion of equality between combining elements, and of equivalence among their atoms, has long been fundamental in chemistry. When the substitution theory arose it was still maintained that the replacements were, atom for atom. But it is now recognized that the replacing power of different kinds of atoms is *unequal*, through a very considerable range. The idea of *variable combining capacity* of atoms and molecules has been worked out with great clearness, and is the distinctive feature of what is now known as the New Chemistry.

**242. Atomicity.**—While certain kinds of atoms interchange with each other as true equivalents, atom for atom, it is found that in other cases it takes two, three, or half a dozen atoms of one kind to equal one of another kind in combining power. To determine these degrees of equivalence of different bodies, we have but to take some one, which will serve as a measure of comparison between them. Hydrogen answers this purpose. It unites with chlorine, atom to atom, forming the molecule of hydric chloride, $HCl$; but oxygen cannot combine with hydrogen in this way; it must take two hydrogen-atoms, forming the molecule of water, $H_2O$. Nitrogen again takes three atoms of hydrogen, forming the molecule of ammonia, $H_3N$; and carbon behaves still differently, demanding four hydrogen-atoms as in the molecule of marsh-gas, $H_4C$. We have, therefore, the four following molecular constructions:

| $HCl$ | $H_2O$ | $H_3N$ | $H_4C$ |
|---|---|---|---|
| **Hydric Chloride.** | **Water.** | **Ammonia.** | **Marsh-Gas.** |

which vary in a regular numerical order. This may seem to be accidental, but it is not so, for, if we take chlorine instead of hydrogen as a measure, we shall get similar results, as follows:

| $NaCl$ | $HgCl_2$ | $SbCl_3$ | $CCl_4$ | $PCl_5$ |
|---|---|---|---|---|
| Sodic Chloride. | Mercuric Chloride. | Antimonic Chloride. | Carbonic Chloride. | Phosphoric Chloride. |

Now this is not something that merely happens among a few selected substances; it illustrates a law that has been traced through the whole chemical field. It is obvious that in the first four groupings, the elements chlorine, oxygen, nitrogen, and carbon, can no longer be regarded as equivalents of each other; nor are the sodium, mercury, antimony, carbon, and phosphorus, of the second group, equivalents of each other. Each element seems to have its own atomic capacity. Hydrogen, sodium, and chlorine, go together in ones; oxygen and mercury take hydrogen and chlorine by twos; nitrogen and antimony take them by threes; carbon takes both by fours; and phosphorus takes its chlorine in fives. This varying atomic capacity is called *atomicity*, and the powers of the different elements in this respect are known as their *atomicities*.

**243. Quantivalence, and its Expressions.** — To these chemical relations the general term *quantivalence* has also been applied; and different modes are employed to indicate the several atomicities of the different elements. They are as follows: bodies whose atomic capacity is

| | | | | | | |
|---|---|---|---|---|---|---|
| One, | are termed | *Monads*, | *Monatomic*, | *Monadic*, | or | *Univalent.* |
| Two | " | *Dyads*, | *Diatomic*, | *Dyadic*, | " | *Bivalent.* |
| Three | " | *Triads*, | *Triatomic*, | *Triadic*, | " | *Trivalent.* |
| Four | " | *Tetrads*, | *Tetratomic*, | *Tetradic*, | " | *Quadrivalent.* |
| Five | " | *Pentads*, | *Pentatomic*, | *Pentadic*, | " | *Quinquivalent.* |
| Six | " | *Hexads*, | *Hexatomic*, | *Hexadic*, | " | *Sexivalent.* |
| Seven | " | *Heptads*, | *Heptatomic*, | *Heptadic*, | " | *Septivalent.* |

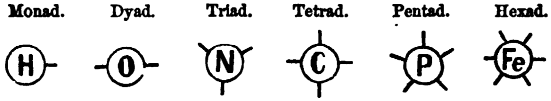
Bodies with a higher atomic capacity than one are said to be polyatomic or multivalent. Hydrogen, in the single compound it forms with chlorine, is assumed as the standard of atomicity.

Quantivalence is also expressed in different ways, as follows:

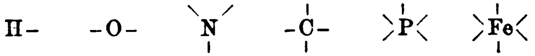
| Monads. | Dyads. | Triads. | Tetrads. | Pentads. | Hexads. |
|---|---|---|---|---|---|
| $H^{I}$ | $O^{II}$ | $N^{III}$ | $C^{IV}$ | $I^{V}$ | $Fe^{VI}$ |
| $Cl'$ | $S''$ | $B'''$ | $Si''''$ | $Bi'''''$ | $Mn''''''$ |
| $F^{-}$ | $Ca^{=}$ | $Sb^{\equiv}$ | $Sn^{\substack{-\\-\\-\\-}}$ | $Ta^{\substack{-\\-\\-\\-\\-}}$ | $Te^{\substack{-\\-\\-\\-\\-\\-}}$ |

With the monadic elements the indices of atomicity are generally assumed and not written.

**244. Bonds.**—To illustrate more clearly the meaning and use of these indices of atomicity in representing chemical combinations and changes, let us represent the atom as a circle. Its attractions, polarities, or quantivalence, may then be symbolized by radial lines, which become the links of union, and appear as follows:



But as the links are the main things, the circles (which were formerly much used) may be dispensed with, and the dashes alone retained to mark the quantivalence, thus:

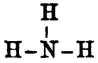


$$\text{H}- \qquad -\text{O}- \qquad \underset{|}{\overset{\diagdown\;\diagup}{\text{N}}} \qquad -\underset{|}{\overset{|}{\text{C}}}- \qquad {>}\overset{|}{\text{P}}{<} \qquad {>}\underset{|}{\overset{|}{\text{Fe}}}{<}$$

These links or dashes are termed *bonds*. When chemism takes effect it is assumed that the bonds of different atoms are joined together, and they are said to be satisfied, or closed; when not so joined they are unsatisfied, or free. The previous examples, in which numerals were used, would be represented as follows by the use of bonds:

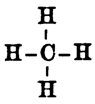
$\text{H}-\text{Cl}$
Hydric Chloride.

$\text{H}-\text{O}-\text{H}$
Water.



$$\text{H}-\overset{\overset{\text{H}}{|}}{\text{N}}-\text{H}$$

Ammonia.



$$\text{H}-\underset{\underset{\text{H}}{|}}{\overset{\overset{\text{H}}{|}}{\text{C}}}-\text{H}$$

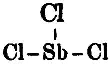
Marsh-Gas.

$Na-Cl$

Sodic Chloride.

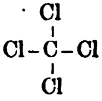
$Cl-Hg-Cl$

Mercuric Chloride.



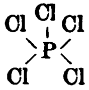
$$\begin{array}{c} Cl \\ | \\ Cl-Sb-Cl \end{array}$$

Antimonic Chloride.



$$\begin{array}{c} Cl \\ | \\ Cl-C-Cl \\ | \\ Cl \end{array}$$

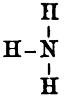
Carbonic Chloride.



Phosphoric Chloride.

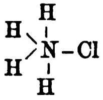
**245. The Bonds control Combination.**—We have here a controlling and limiting principle of all chemical changes. In every transformation each bond requires to be satisfied, and an atom can link itself to others only to the extent of its bonds. Only those elements can unite with each other, atom to atom, which have the same number of bonds. "The hydrogen, sodium, and chlorine atoms have only one bond or pole, and hence, in combining with each other, they can only unite in pairs. The oxygen-atom has two bonds or poles, and can combine, therefore, with two hydrogen-atoms, one at each pole. The mercury-atom has also two bonds, and takes, in a similar manner, two atoms of chlorine; but it can only combine with a single atom of oxygen, for the two poles of one just satisfy the two poles of the other. Again, the atom of carbon has four bonds, which may be satisfied by either four atoms of hydrogen, or four atoms of chlorine, or two atoms of oxygen; or one atom of oxygen and two of chlorine; or, lastly, one atom of oxygen and two of hydrogen. Further, the atom of phosphorus has five bonds, and holds five atoms of chlorine, or three atoms of chlorine, and one of oxygen." On this theory, we view every chemical compound as a molecule which can exist separately in consequence of the equipoise of all its attractions, as shown by the closing of the bonds of all its atoms.

**246. Varying Quantivalence in the Same Element.**—Elements are not limited to one degree of quantivalence. Thus nitrogen may act either as a triad or a pentad; iron as a dyad, tetrad, or hexad, and most of the other elements may assume different quantivalent relations. It is remarkable that the same element in changing its quantivalence changes its chemical relations almost as if it became a new element, giving rise to widely different classes of compounds in its different states of atomicity. Thus triatomic nitrogen in ammonia, and



$H-\overset{H}{\underset{H}{N}}$

Ammonia Gas.

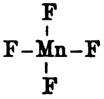


Ammonic Chloride.

pentatomic nitrogen in ammonic chloride, give rise to two series of compounds, with a marked contrast of properties. Again, manganese unites with fluorine as a dyad, a tetrad, and a hexad, as shown by the following graphic symbols; and the difference between the chemical relations of the

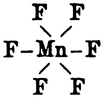
$F-Mn-F$

Mn. Dyadic.



$F-\overset{F}{\underset{F}{Mn}}-F$

Mn. Tetradic.

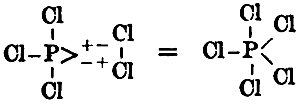


Mn. Hexadic.

diatomic and the hexatomic-atom is said to be "almost as great as that between the atom of zinc and the atom of sulphur." But the replacing and atom-fixing power of an element in its different states is very unequal. Thus, sulphur acts as a hexad, and lead as a tetrad; but the most common condition of both is diatomic. Nitrogen is a pentad, but much more frequently a triad. Bodies have thus a higher and lower quantivalence, and it has been proposed to limit the term *atomicity* to the highest quantivalence that they ever exhibit. But this is a less important property of an element than the leading or prevailing quantivalence.

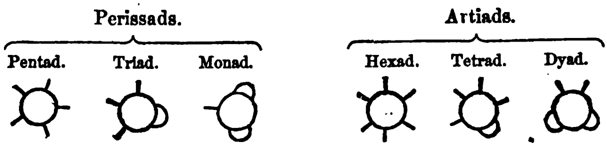
**247. Perissads and Artiads.**—Variation in the degrees of quantivalence in an element is always dual, that is, it increases or diminishes by two. Hence, there are two series of steps, an odd series—one, three, five, and seven, and an even series—two, four, and six. Elements, whose quantivalence is odd, are termed *perissads;* elements, whose quantivalence is even, are called *artiads.* It seems to be a principle, almost, if not quite universal, that an artiad can never become a perissad, nor a perissad an artiad. There may be a few exceptions, but the distinction is regarded as fundamental, and as so completely separating chemical bodies into two great divisions, that it is taken as the basis of present classification.

**248. Theory of Change by Pairs.**—The analogies of polarity offer an explanation of the changes of quantivalence by pairs of attractions. When the opposite poles of a magnet are brought together they neutralize each other; and so it is thought that the bonds of an atom, when not closed by other atoms, may neutralize and satisfy each other, in pairs—conversely, the neutralized bonds may be aroused by induction of more strongly polarized atoms (125). Thus, phosphorus unites with chlorine both as a triad and a pentad; and, if the atoms of the chlorine molecule are assumed to be in opposite polar states, the change of $P^{III}$ to $P^{V}$ is explained, thus:



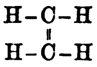
$$\mathrm{Cl{-}}\overset{\mathrm{Cl}}{\underset{\mathrm{Cl}}{\mathrm{P}}}>\begin{smallmatrix}+&-\\-&+\end{smallmatrix}\begin{matrix}\mathrm{Cl}\\|\\\mathrm{Cl}\end{matrix} = \mathrm{Cl{-}}\overset{\mathrm{Cl}}{\underset{\mathrm{Cl}}{\mathrm{P}}}\langle\begin{matrix}\mathrm{Cl}\\\mathrm{Cl}\end{matrix}$$

The fact that a single bond is never suppressed is thus accounted for, and a reason given why artiads and perissads are inconvertible. As the bonds can only be saturated in pairs, a pentad can become a triad and a monad successively; and a hexad may be converted into a tetrad or a dyad, as follows:



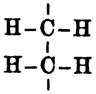
**249. The Free State of Elements.** — As an atom or a molecule can only exist separately when its bonds are all closed, that is when saturated, it follows that perissads cannot exist free. The odd bond must be satisfied. In hydrogen gas, therefore, the condition is not atomic, as H – is impossible; but it is molecular, or H – H. So free chlorine, Cl – Cl, and sodium, Na – Na, are self-saturated molecules. As the even bonds of the artiads can close each other, these elements may exist as separate atoms; oxygen being either O = O, or O >.

**250. Importance of Mode of Linking.** — The quantivalence of a molecule does not depend entirely upon the atomicity of its elements, but partly upon the manner in which they are united. When multivalent atoms are connected together only by single bonds, the remaining bonds will be free, and determine the quantivalence of the group. Thus the molecule $C_2H_4$ may be saturated, or diatomic, accordingly as two bonds of the carbon-atoms are disposed of. This is seen by comparing the following symbols:



$$\begin{array}{c} H-C-H \\ \| \\ H-C-H \end{array}$$

Saturated.



$$\begin{array}{c} | \\ H-C-H \\ | \\ H-C-H \\ | \end{array}$$

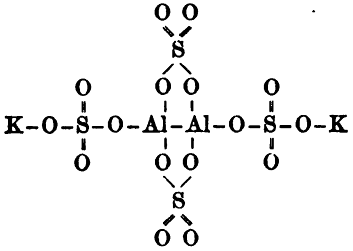
Diatomic.

**251. Structure of Molecules.**—On this view it is impossible to avoid the idea of the great importance of the grouping of atoms in molecules. If the relations among atoms are such that they can be most accurately represented by the mechanical conception of bonds and clamps, that of structure in the molecules inevitably follows. These structures are of different orders. With monads we can only get molecules of the simplest construction, in which the atoms are paired, as K – Cl, H – I. As a monad has but one bond, it can never join other atoms together; but when dyads are introduced the molecular structure becomes more complex. The dyad performs a linking function, and in union with monads produces molecular chains. Oxygen acts extensively in this way, as in

$$\mathrm{H-O-H} \qquad\qquad \mathrm{H-O-Ca-O-H}$$

Water. Calcic Hydrate.

and, by introducing more oxygen-links, such chains may be indefinitely extended. With atoms of higher quantivalence the complexity is increased in a still greater degree, the multivalent atom playing the part of a nucleus. The following scheme represents the constitution of common alum as a saturated molecule:



Potassic-Aluminic Sulphate (Alum).

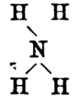
The double atom of aluminium is the nucleus of the group, and combines four subordinate groups, each having a nucleus of hexadic sulphur. It matters nothing how such a scheme is drawn, so that the atomicities are all satisfied, but from the way such complex molecules break up in decomposition it is inferred that there must be some definite order of arrangement among the atoms.

## § 4. *Theory of Radicals.*

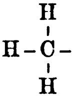
**252. Simple Radicals.**—The term radical has long been applied to any chemical body which is regarded as a common ingredient, or basis of a series of compounds. Thus potassium, sulphur, and, in fact, any element may be taken as the starting-point, or root, of such a series. The simple radicals, or elements, may be divided into two great classes, which stand in opposite relations, the metals and the non-metals, the former being electro-positive, or positive radicals, and the latter electro-negative, or negative radicals.

**253. Compound Radicals.**—But it has been established that there are groups of elements so bound together that they play the part of simple bodies, and are therefore called *compound radicals;* thus carbon and nitrogen combine to form the radical cyanogen CN, which is the root of a series of compounds much resembling those formed by chlorine. Ammonium, $NH_4$, is a compound radical which behaves in chemical reactions closely like the metals, combining with chlorine, sulphur, and cyanogen. Methyl, $CH_3$, is the radical of methylic alcohol; and ethyl, $C_2H_5$, is the root of ethylic alcohol, both of which are traceable through numerous affiliated compounds. These compound radicals are classed as positive and negative, like the simple ones.

**254. Quantivalence of Compound Radicals.**—Compound radicals also obey the laws of quantivalence like simple radicals. In general they cannot be isolated, as they are unbalanced molecules; but some of them pair with each other like elementary atoms, forming saturated molecules which can exist separately. The radical hydroxyl, $H-O-$, cannot, as it has an unsaturated bond, exist free, but coupled as $H-O-O-H$ it forms the compound known as hydric peroxide. The compound radicals interchange with each other, and with the simple radicals, under the usual limitations of atomicity, or, according to the number of free bonds. As represented by the graphic symbols, the following radicals are monatomic:

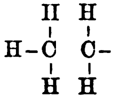


Ammonium.



$H-\overset{H}{\underset{H}{C}}-$

Methyl.



$H-\overset{H}{\underset{H}{C}}\ \overset{H}{\underset{H}{C}}-$

Ethyl.

### § 5. *Theory of Acids, Bases, and Salts.*

**255. The Old View.**—These numerous and important bodies were long explained in a very simple way on the dual theory, already noticed. The primary elements were divided into the metals and non-metals, which, uniting with each other in pairs, give rise to binary compounds, acids and bases. Acids are sour, corrosive substances, that turn vegetable blue colors to red, and have a strong chemical attraction for bases. Bases, on the other hand, are a class of bodies, (including alkalies, which have a hot, acrid taste, and restore the blues discharged by acids,) that are marked by their powerful chemical attraction for acids. The union of acids and bases gives rise to the ternary compounds known as salts—bodies, generally, with a saline taste, and in which the acid and basic constituents are partially or totally neutralized. For example, the element oxygen, "the centre of the chemical world," and long regarded as the acidifying principle of Nature, unites with sulphur to form sulphuric acid, $SO_3$. Oxygen also combined with potassium to form basic potash, KO. These binaries then paired in the production of the ternary salt, sulphate of potash, $KO, SO_3$.

Even in salts affinity is often not exhausted. They may be again coupled, producing quaternary compounds, or double-salts. Most of the bodies of Nature were viewed as composed of these four great groups, primaries, binaries, ternaries, and quaternaries; and chemistry, for half a century, consisted in extending chemical knowledge under the guidance of this system. But, as facts have accumulated, it has undergone a profound modification.

**256. Water in Relation to the Theory.**—Water was long supposed to act only as a solvent medium, facilitating the reactions of other bodies, but not participating in the changes, except that its particles were sometimes taken up, and appended to other compounds, as "water of hydration," or "water of crystallization." But at length it began to be recognized that the elements of water are themselves seriously implicated in the transformations. It turned out, in fact, that, in regard to the constitution of acids, alkalies, and salts, water holds a controlling relation; its molecule being the pattern upon which they are all constructed. It was, moreover, found that the union of acids and bases in the production of salts is not a direct combination, or pairing; but that acids, bases, and salts, are all alike formed by the substitution of different kinds of atoms for atoms in the water-group; the replacements occurring without disturbing the type of the water-molecule. The water-group may be regarded either as a molecular chain, with hydrogen-atoms at each end, linked by dyadic oxygen, $H-O-H$; or, as a compound of the radical hydroxyl $H-O-$, with hydrogen; and the substitution may be either for one hydrogen-atom, for the two hydrogen-atoms, or for the hydroxyl group.

**257. Constitutions of Acids.**—By comparing the water-molecule with acid molecules, the relations are shown at a glance:

| | |
|---|---|
| Water. | $H-O-H$ |
| Hypochlorous Acid. | $H-O-Cl$ |
| Nitric Acid. | $H-O-(NO_2)$ |

Here the hydrogen at one end of the water-chain has been simply replaced by chlorine, and an acid molecule is the result. The chlorine is a simple radical, powerfully electro-negative, which, by replacing hydrogen in the water-molecule, produces an acid. Nitryl ($NO_2$) is a negative compound radical, which also replaces hydrogen in the water-molecule, producing the powerful nitric acid. An acid molecule is therefore one in which a negative radical, simple or compound, is united by oxygen to hydrogen, and it has the general formula $\bar{R}-O-H$.

**258. Constitution of Bases.**—When pure metallic sodium is added to pure water, energetic chemical action ensues, hydrogen is set free, and the water becomes alkaline or basic. If it is evaporated, a white powder is obtained, which is caustic soda, or sodic hydrate. We begin with sodium and water, and get sodic hydrate thus:

$$\begin{array}{c} H-O-H \\ Na-O-H; \end{array}$$

that is, the reaction has consisted simply in the substitution of Na for H in the water-molecule, which has not changed its type. But, as the sodium is a diatomic molecule, it engages two molecules of water, as may be graphically represented :

$$\begin{array}{ccccccc} H-O-H & & Na & & Na-O-H & & H \\ & + & | & - & & + & | \\ H-O-H & & Na & & Na-O-H & & H \end{array}$$

The new molecules have thus exactly the same structure as the old. Had potassium been used, instead of sodium, the reaction would have been the same, with the production of another basic molecule. But sodium and potassium are *positive* radicals. A basic molecule, therefore, is one in which a positive radical, simple or compound, is united by oxygen to hydrogen, and its general formula is $\overset{+}{R}-O-H$.

**259. Constitution of Salts.**—If, now, an acid molecule and a basic molecule are brought together, a strong reaction takes place ; but, again, it is a substitution that does not impair the molecular type. We get a salt which has the general formula $\overset{+}{R}-O-\overset{-}{R}$. Thus, an

$$\begin{array}{l} \text{acid,} \\ \text{and a base} \end{array} \quad \left.\begin{array}{l} \overset{-}{R}-O-H \\ \overset{+}{R}-O-H \end{array}\right\} \text{give} \left\{\begin{array}{l} \overset{+}{R}-O-\overset{-}{R} \\ H-O-H \end{array}\right. \quad \begin{array}{l} \text{a salt, and} \\ \text{water.} \end{array}$$

Compounds in which a positive element, or radical, is linked to a negative element or radical by oxygen, or some analogous dyad, are termed salts.

**260. Hydrates.**—On the foregoing view acids and bases belong to the same class of compounds, and are called hydrates—acid hydrates and basic hydrates. Caustic potash and nitric acid are opposite extremes of the same series which are connected by bodies of intermediate gradation. Hydrogen is an essential constituent of all acids and bases. Salts contain no hydrogen, and possess neither acid nor basic properties.

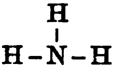
**261. Quantivalence of Hydrates.**—The hydrogen, which is directly linked to the atomic group by oxygen in acids, is termed basic hydrogen; that in bases, acid hydrogen. It is readily replaceable in the former case by other positive elements; in the latter case by other negative elements or radicals. Hydrates are univalent, bivalent, trivalent, etc., according to the number of these replaceable hydrogen-atoms, or hydroxyl groups; and acids are said to be mono-, di-, or tri-basic; and bases, mon-, di-, or tri-acid, in the same conditions.

**262. Kinds of Acids and Bases.**—Acids or bases in which all the oxygen (or analogous element) performs a linking function, are called *ortho-*, those which also contain oxygen that is not linking, are termed *meta-*, acids or bases. The atoms of ternary molecules may be connected by the negative dyads, sulphur and selenium, as well as by oxygen, giving rise to sulphur and selenium acids, bases, and salts.

**263. Classes of Salts.**—Salts containing neither acid nor basic hydrogen are said to be *normal.* Acid salts are those which contain basic hydrogen, and manifest acid reactions; basic salts contain acid hydrogen, and produce basic effects. Double salts are such as contain two or more positive atoms.

**264. Anomalous Bodies.**—As common salt, the substance which, above all others, was long considered as the type of saline character, contains no oxygen whatever, it cannot properly be included in this class of bodies. It consists of one atom of each of the monad elements, sodium and chlorine, directly united. Substances of analogous composition have been called *haloids*—bodies resembling salt. As the compounds of hydrogen with chlorine, and other elements analogous to it, likewise contain no oxygen, though often termed acids, they must also be excluded from this group as above defined. They are sometimes distinguished as *hydracids*.

**265. The Ammonia Type.**—In acids, bases, and salts, the radicals are linked by dyads, but triadic elements, as nitrogen, phosphorus, or arsenic, may perform a similar linking function, and then we have a corresponding series of bodies on a new type. Nitrogen is the nucleus of the most important group, and its molecule in ammonia,



$$\begin{matrix}H\\|\\H-N-H\end{matrix}$$

is the type of a large class of compounds. If the hydrogen is replaced by negative radicals, an *amide* is produced; if by positive atoms, an *amine* results; if by one positive and one negative radical, an *alkalamide* is the product. By thus substituting simple or compound radicals for the hydrogen of the ammonia-molecule, we get the derived ammonias. If we write ammonia as $\left.\begin{matrix}H\\H\\H\end{matrix}\right\}N$, and then substitute for its hydrogen the negative radicals, cyanogen, iodine, and chlorine, the formation of the amides will be made clear:

$$\left.\begin{matrix}(CN)'\\H\\H\end{matrix}\right\}N \qquad \left.\begin{matrix}I\\I\\H\end{matrix}\right\}N \qquad \left.\begin{matrix}Cl\\Cl\\Cl\end{matrix}\right\}N$$

Cyanamide. Din-iodamide. Tri-chloramide.

By replacing the hydrogen with positive radicals, we get the amines, as follows:

$$\left.\begin{matrix}K\\H\\H\end{matrix}\right\}N \qquad \left.\begin{matrix}Na\\Na\\H\end{matrix}\right\}N \qquad \left.\begin{matrix}Rb\\Rb\\Rb\end{matrix}\right\}N$$

Potassamine. Di-sodamine. Tri-rubidamine.

## § 6. *Theory of Isomerism and Allotropism.*

**266. Inorganic Chemistry in Relation to Theory.**—Chemical science has been long divided into two great branches—inorganic chemistry, which treats of non-living or mineral substances, and organic chemistry, which treats of matter that composes the parts of organized things. In the former department the chemist deals with all the elements of Nature in their simple physical conditions; in the latter he is occupied with only a very few elements in circumstances of great obscurity and complexity. In fact, organic chemistry was long regarded as an impossibility, under the belief that the vital force dominates in the organic sphere, and suspends the ordinary laws of chemical action. It was therefore natural, and indeed inevitable, that inorganic chemistry should be cultivated first, and that the earlier theories of the science should be framed upon the knowledge obtained by studying the simpler and more general phenomena. Yet the domain was partial, and the knowledge limited; organic chemistry was a legitimate and most important division of the science, and its numerous and remarkable facts being left out, the prevailing theories were necessarily defective.

**267. Organic Chemistry in Relation to Theory.**—But it was impossible to confine the chemists within these early and arbitrary limits; they pressed into the organic field, and were rewarded by the discovery of multitudes of new substances, many of them of great importance. They also made an unexpected conquest by forming, artificially, in the laboratory, various compounds which had hitherto been regarded as producible only under the influence of life. Much ingenuity was, however, at first expended in the effort to bring the new facts into harmony with preëxisting theoretical views. The efforts, however, proved futile. A new chemistry sprang up in the new province, which, instead of being subordinated to old theories, powerfully reacted upon them. And thus, from a neglected region, long supposed to lie beyond the bounds of the science, there came an influence that has changed its whole theoretical character. The modern ideas that are distinctive of the new system — changes by substitution, types, unitary groups, atomicity, and the controlling importance of molecular structure—have all arisen through the modern investigation of organic substances.

**268. The Organic Elements.**—Four substances make up the main bulk of organized bodies throughout the entire vegetable and animal kingdoms, viz., hydrogen, oxygen, nitrogen, and carbon. The properties of these bodies are remarkable. The three gases have never been condensed to the liquid or solid state by any application of mechanical force, although they are constantly reduced to these conditions by chemical action. Carbon, on the other hand, is an equally invincible solid, never having been liquefied or vaporized in its separate state. Hydrogen is the most attenuated of bodies, the unit of the chemical system, and the most widely-diffused element in Nature. Oxygen is the most abundant element on the globe we inhabit, has an extreme range of attractions, and forms compounds of all grades of stability. Nitrogen performs peculiar offices of the highest importance in the world of life, giving quality to the most complex and changeable organized compounds. Carbon is the common solidifying element in all organized products, and by its peculiar chemical relations stamps the character of this division of chemistry. Hydrogen is monadic, oxygen dyadic, nitrogen triadic, and carbon tetradic. The latter element, by its high multivalence, combines with itself in interminable series of radical groups, which become the skeletons or nuclei of a countless host of compounds by linking with atoms and groups of other elements. Organic chemistry, under this title, has in fact now disappeared, and so important is the part played by carbon that this division of the subject is known as the

"Chemistry of the Carbon-compounds." Prof. Cooke, indeed, does not hesitate to say that "the number of known compounds of this one element is far greater than those of all the other elements besides."

**269. Isomerism.**—The old conditions of analytic inquiry here obviously failed. It was not enough merely to analyze organic substances, and state the elements and the proportions of the elements that they contained. Analysis, in fact, now broke down so completely as to leave no alternative to chemists but to seek the explanation of the properties of bodies in their atomic arrangements; for compounds of the most diverse properties were found to consist of exactly the same elements in exactly the same proportions. Butyric acid, an oily liquid, not easily inflammable, which has the disgusting smell of rancid butter, and gives the acid reaction, has the formula $C_4H_8O_2$; while acetic ether, a limpid liquid, non-acid, easily inflammable, and having the pleasant, fruity smell of apples, has also the formula $C_4H_8O_2$. These substances are therefore said to be *isomeric*, a term meaning *equal measure*. There is no way of explaining this difference of properties, except on the theory that the constituent atoms are differently grouped in the two cases. And this is proved by acting on the two molecules with chemical agents, when they break up in very different ways, and give rise to different products. Isomeric compounds are often convertible into each other without loss or addition; their different properties must therefore be ascribed, not to the presence or proportions of certain elements, but to the influence of molecular clustering and structure.

**270. Kinds of Isomerism.**—Isomeric phenomena are so important that they have been discriminated as of different kinds. If bodies have the same absolute composition, as in the example just quoted, they are said to be *metameric* compounds. But substances sometimes have not the same atomic composition, although represented as identical on a percentage scale. They have only the same *proportions* of elements, and are then said to be *polymeric* compounds. Isomeric bodies are called *isomerides* or *isomers.*

**271. Allotropism.**—Closely allied to isomerism, in fact, the same thing, only limited to elementary bodies, are the phenomena of allotropism, or allotropy. The word means *different states,* and denotes different conditions, into which the elements are observed to pass with the manifestation of diverse properties. Thus phosphorus, sulphur, and carbon exist, each in several different allotropic forms, with totally unlike sets of characters. It was at first supposed that but few of the elements were allotropic, but it is now found that a considerable number of them take on this doubleness of condition. The only theory of these effects hitherto offered, is that of varying atomic or molecular arrangement.

## § 7. *Theory of Combining Volumes.*

**272. Space-Relations of Molecules.**—It has been stated that the physicist and the chemist agree in regarding molecules as actual things, pieces of matter, amazingly minute, but just as real as planets and stars are to the astronomer. Thus far we have considered them only in relation to weight; but if they are things of weight they must occupy space, and have dimensions. Something has been done toward elucidating this problem of the space-relations of molecules; and physics and chemistry have both contributed to the result.

**273. The Law of Avogadro.**—When a given amount of heat is applied to a given amount of matter in the solid or liquid state, the expansions are unequal. If, for example, the same amount of heat is applied to equal volumes of water, alcohol, and ether, they expand differently; but if these substances are converted into vapor, and then the same amount of heat is applied to equal volumes, a new result appears: the vapors now all expand alike. In the change to the gaseous state the molecules have got free of each other's attractions, and enter upon a common condition of mutual repulsion. In this state all gases and vapors obey common laws, both in expanding under the influence of heat, and in contracting under the influence of pressure. What can be the cause of these remarkable uniformities? This question was answered by the Italian physicist, Avogadro, as early as 1811, as follows: "*Equal volumes of all substances when in the state of gas, and under like conditions of temperature and pressure, contain the same number of molecules.*" This is known as Avogadro's law. The law of Avogadro cannot be directly proved, but it is indirectly established by the most convincing evidence; and it harmonizes and explains so great a number of physical and chemical facts, that it is now accepted by both physicists and chemists as a fundamental principle.

**274. Size of Molecules.**—That molecules have magnitudes is self-evident, and if the principle be true that equal numbers occupy equal spaces, it is inferable that they all have equal magnitudes. What those dimensions are may be thought an impossible problem, and certainly it must be one of great difficulty, and uncertain results. Yet the ablest physicists do not regard its difficulties as insuperable, and claim to have already arrived at approximate conclusions that are entitled to reasonable confidence. Great advances have been made in recent times in minute measurements. Time is measured in millionths of a second, and lines have been ruled on glass plates numbering 224,000 to the inch—several times finer than the scale of wave-lengths. From various lines of research of exquisite delicacy, among others, the relations of light to thin films, the conclusion has been reached that the diameters of gaseous molecules will not greatly vary from the $\frac{1}{500,000,000}$ of an inch. According to a theorem of molecular mechanics deduced by Clausius, the number of molecules in a perfect gas, at the freezing-point, and with a barometric pressure of thirty inches, is about one hundred thousand million million million, or $10^{23}$ to a cubic inch. Sir William Thomson, who has been prominent in these investigations, says: "If we conceive a sphere of water as large as a pea to be magnified to the size of the earth, each molecule being magnified to the same extent, the magnified structure would be coarser grained than a heap of small lead shot, but less coarse grained than a heap of cricket-balls."

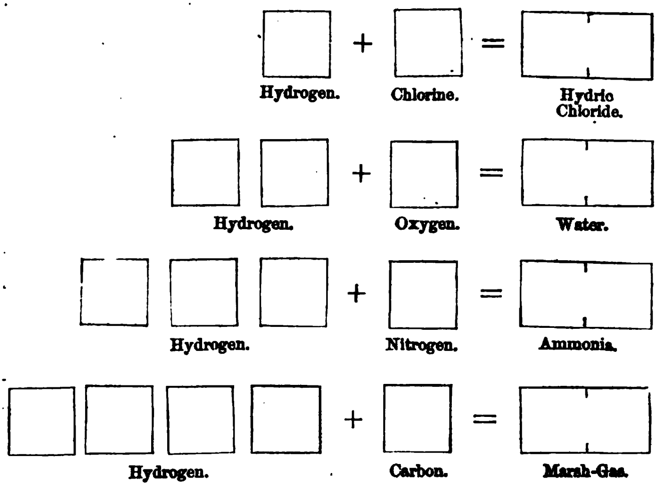
**275. Chemical Application of Avogadro's Principle.**—If equal measures of two different gases or vapors contain the same number of molecules, then we have but to weigh these equal volumes to get the relative weight of the molecules. For example, a cubic inch of oxygen weighs sixteen times as much as a cubic inch of hydrogen, under the same conditions; but, if in every cubic inch there is the same number of molecules, each molecule of oxygen must weigh sixteen times as much as each molecule of hydrogen. We have thus a simple means of determining the molecular weight of all bodies that are capable of passing into the aëriform state.

**276. The Unit of Molecular Weight.**—If the hydrogen-*molecule* were taken as the standard, then the specific gravity of any gaseous body compared with it would give its molecular weight. But the *half-molecule* of hydrogen has been adopted as the unit, or 1, so that the hydrogen-molecule will have to be represented by 2. This makes it necessary to double the specific gravities of gases in order to get the molecular weight. The volume of the hydrogen-molecule being represented by 2, as all molecules have the same volume, they must also be represented by 2. As the molecule of hydrogen weighs 2, the molecule of oxygen, which is sixteen times heavier, weighs 16 times 2, or 32. The specific gravity of nitrogen, compared with hydrogen, is 14; its molecular weight is therefore 28. As density is weight referred to a unit-volume, a litre of hydrogen is taken as the unit of density of gases, and is called a *crith.* The numbers expressing specific gravity also express the density or weight in criths, consisting of one litre of the gas or vapor, under standard conditions, thus:

| | Hydrogen. | Nitrogen. | Oxygen. | Chlorine. |
|---|---|---|---|---|
| Specific Gravity. | 1 | 14 | 16 | 35.5 |
| Density. | 1 crith. | 14 criths. | 16 criths. | 35.5 criths. |

**277. Physical Verifications.**—This method is of great importance in chemical investigations, where molecular weights and formula are to be determined. Analysis, as we have before seen, gives us only the proportions of elements in a compound. It tells us, for example, that water consists of 88.89 parts, by weight, of oxygen, and 11.11 parts of hydrogen, but this is only a ratio, and may be expressed as 8 to 1, or 16 to 2, or 24 to 3, so that the actual molecular weight of the water might be either 9, 18, or 27. But if now water is vaporized, and the vapor weighed, its density turns out to be 9 times that of hydrogen; and this number multiplied by 2 gives 18 as the actual molecular weight of water. The molecular weights of solid and liquid substances can only be chemically ascertained by combining them with other substances, and finding the lowest proportions in which such combination ever takes place, which is the molecular weight. Such results are, however, indecisive, as new combinations may give new numbers. But, if the substance is capable of being vaporized, the indications that may be obtained are usually regarded as conclusive. It may here be stated that there is a kindred closeness in other numerical relations of physics and chemistry. A striking connection is found to subsist between the atomic weights and the specific heats of the elements, known as *atomic heat.* That is, the numbers expressing the relative amounts of heat required to raise equal weights of iron, copper, and lead, for example, through equal degrees of temperature, coincide with the atomic numbers of these elements. Moreover, the quantities of electricity expended in decomposing compounds are found to be also in definite relation to the atomic weights of the bodies set free.

**278. Combining Volumes.**—Gases combine by volume in very simple ratios; in some cases in equal measures without condensation; but if condensation occurs it is by whole units, as 2 to 1, 3 to 1, or 4 to 1, as is illustrated in the following cases:



**279. Theory of these Effects.**—The foregoing ratios of combining volume are simple results of experiment; but if Avogadro's law is assumed, that equal gas-volumes contain equal numbers of molecules, the theory of quantivalence explains the effects. In the first case we have monadic atoms with diatomic molecules $H-H$ and $Cl-Cl$, and in equal volumes an equal number of these molecules. When the gases are mingled, the molecules interchange atoms producing $H-Cl$ and $H-Cl$, but, as the number of molecules remains the same, the volumes remain unaltered. In the second case we have the dyad oxygen, the molecule of which is $O{=}O$. Each of its atoms links two of hydrogen, forming the triatomic molecule $H_2O$. The total number of molecules is thus diminished a third, and the three volumes are consequently reduced to two. In the third example we have triadic nitrogen, the molecule of which is $N{\equiv}N$. Each nitrogen-atom takes three hydrogen-atoms, forming ammonia, $H_3N$. All the molecules at first contain two atoms, and the resulting molecules contain four. There is, therefore, but half the number of molecules, and the four volumes are reduced to two. Lastly, each atom of the tetrad carbon molecule, $C{\equiv}C$, unites with four atoms of monadic hydrogen, and the resulting molecule contains five atoms. The number of molecules formed equals the number of carbon-atoms, or twice the number of the carbon-molecules, and hence the five volumes are condensed to two.

# CHAPTER X.

## THE CHEMICAL NOMENCLATURE.

**280. The Science reflected in its Language.**—The terms used in chemistry bear the impress of the various theoretical stages of the science. Some of them, as gold, silver, iron, were applied to substances thousands of years ago, before the science had taken a separate form. The alchemists were the first chemists, and they worked under the mystical influence of astrology. Terms still survive that indicate the fancied relations of substances to celestial bodies. Quicksilver was associated with Mercury; silver with Luna or the moon (hence lunar caustic); and crocus

Martis, a compound of iron, is a vestige of the old association of this metal with Mars. The alchemists had a crude theory of the action of spirits in Nature, and named various products accordingly, as spirit of wine, spirit of salt, spirit of hartshorn, spirit of nitre, etc. The first general chemical theory, that of phlogiston, gave rise to a terminology which has disappeared with the system, and which renders many of the chemical books of the eighteenth century almost unintelligible to a modern student. The system of naming chemical substances called the *Nomenclature*, which originated with the French about a hundred years ago, has been of immense service, both in the advancement and the diffusion of the science. When the facts of chemistry were comparatively few, and its theory simple, the terminology, which conformed to the dual doctrine, was also simple and highly effective. But as facts of all orders rapidly multiplied, and assumed new relations, the old system of expression was disturbed; and now, with the changes of theory, the nomenclature has been unsettled at various points, and there is some want of uniformity among authorities in the use of chemical terms. The main principles, however, remain in full force.

**281. Naming the Elements.**—The names of the elements generally given have been expressive of some leading quality, real or imaginary. Thus, oxygen, as has been stated, received a name signifying *acid-former*, while chlorine takes its name from its greenish color; iodine, from its purple vapor, and phosphorus from its being luminous in the dark. Analogy of properties is sometimes indicated by similarity of termination, as chlor*ine*, brom*ine*, iod*ine*; while the metals discovered in modern times are marked by the termination *um*, as platinum, thallium, etc.

**282. Naming of Compound Radicals.**—These substances, which, as we have seen, are analogous to elements, are generally named from one or more of their constituents, or from some compound into which they enter. The terminal syllable, generally, is *yl*. Thus, the radical composed of one atom of hydrogen and one of oxygen is called *hydroxyl*, and that composed of one atom of oxygen and one of carbon, *carbonyl*. Ethylene and benzylene are examples of compound radicals whose names terminate in *ylene*. Exceptions to the forms given are found in the case of cyanogen, and in the numerous compounds formed of carbon and hydrogen, or of carbon, oxygen, and hydrogen, whose names frequently bear reference to the number of their carbon-atoms, as, for example, trityl, tetryl, etc.

**283. Naming of Binary Compounds.**—Binary compounds, strictly speaking, result only from the union of two elementary substances, but the term is frequently extended to include combinations of two compound radicals. Thus, silicon and fluorine combine to form silicic-fluoride; while methyl and ethyl form methylic-ethide. All of these compounds are named by placing the positive element *first*, and the negative element, with its termination changed to *ide*, after it. Thus:

| | | | |
|---|---|---|---|
| Compounds of | Chlorine | are called | Chlor*ides*. |
| " | Bromine | " | Brom*ides*. |
| " | Iodine | " | Iod*ides*. |
| " | Fluorine | " | Fluor*ides*. |
| " | Sulphur | " | Sulph*ides*. |
| " | Nitrogen | " | Nitr*ides*. |
| " | Phosphorus | " | Phosph*ides*. |
| " | Antimony | " | Antimon*ides*. |
| " | Carbon | " | Carbon*ides*. |

The termination of the name of the positive element is changed to *ic*, except in compounds, in which the positive element unites with the negative element in variable proportions, when the ending *ic* is confined to the compound containing the smaller proportion of it, while the termination *ous* expresses the larger quantity of the positive element. Thus:

| | |
|---|---|
| Ferr*ous* oxide, | $FeO$. |
| Ferr*ic* oxide, | $Fe_2O_3$. |
| Stann*ous* chloride, | $SnCl_2$. |
| Stann*ic* chloride, | $SnCl_4$. |

In some cases the terminations *ous* and *ic* are affixed to the names of the elements, as, for example, in the well-known compounds sulphurous and sulphuric oxide. When the name of the positive element is not derived from the Latin or Greek language it is translated into the former before changing the termination; thus, the Latin for gold is *aurum*, and it forms two compounds with chlorine, one of which is termed aurous, and the other auric chloride. When the number of compounds formed of two elements exceeds two, *hypo*, under, and *per*, over, are employed to distinguish them; thus, a compound containing less oxygen than chlorous oxide is known as hypochlorous oxide, while one containing more oxygen than chloric oxide would be known as perchloric oxide.

**284. Prefixes.**—A system of naming much used in the following pages consists in the use of numerical prefixes, expressing the number of atoms of the element. The compounds of nitrogen and oxygen, all containing two atoms of nitrogen, united with respectively one, two, three, four, and five atoms of oxygen, are distinguished as nitrous monoxide, dioxide, trioxide, tetroxide, and pentoxide; while a compound containing three atoms of iron and four atoms of oxygen is termed tri-ferric-tetroxide. An exception to the previous rules is found in compounds consisting of carbon and hydrogen—these are so very numerous that the methods given cannot be rigidly applied. The termination adopted is generally *ene*.

**285. Naming of Salts, Acids, and Bases.**—The constitution of these compounds has been already explained (257).

and the method of naming them is a modification of the old system, which was derived from the dual view of their constitution. They are named, like binaries, from their constituent atoms. In the case of the negative element the termination is changed to indicate that the atoms are linked by oxygen. These negative terminations are *ate* and *ite;* the positive element follows the rule given (283). Thus, hydric nitride becomes, by the introduction of *more* oxygen, hydric nitrate; by *less* oxygen, hydric nitrite—both acids. In salts the element which replaces the hydrogen of the acid becomes the first term of the name. For example, when the element sodium replaces the hydrogen of hydric nitrate, we obtain sodic nitrate; when it replaces the hydrogen of hydric nitrite, we obtain sodic nitrite. Bases are named like the salts, water taking the place of the second term of the name. Thus, the base which consists of calcium and hydrogen, linked by oxygen, is termed calcic hydrate.

The common names of the acids are derived from those of binary compounds containing oxygen by merely substituting the word acid for the word oxide, thus ignoring, in the naming of the compound, the oxygen; but, when the linking element is not oxygen, but some of its analogues, a prefix is used. Arsenic acid is composed of arsenic and hydrogen, linked by oxygen; sulpho-arsenic acid of arsenic and hydrogen linked by sulphur.

**286. Naming of Amides, Amines, and Alkalamides.**—It will be remembered that these bodies are derived from ammonia (265) by replacing one or more of the hydrogen-atoms by other elements or radicals. They are named by joining the names of the substituted elements, either with or without their terminal syllable, with the termination *amide* or *amine.* Thus, we have Cyanamide, Potassamine: and the replacing of more than one element or radical is indicated by numerical prefixes, thus: Di-iodamide, Di-sodamine; and, when these compounds are derived from more than one molecule of ammonia, the numerical prefix is inserted between the names of the elements or radicals taking the place of hydrogen and the word amide or amine.

**287. Chemical Formula.**—The notation and use of symbols have been already explained (236). Chemical composition and reactions are expressed by writing them together; and such written expressions are called chemical formula. An *empirical* formula is one which states only what substances and what proportions of them or number of atoms form a compound; a *rational* formula aims to express the manner of atomic grouping, or the way the elements are combined. The empirical formula for alcohol is $C_2H_6O$, the rational formula is $C_2H_5.OH$, a compound of ethyl and hydroxyl. When the atoms of a group are more closely connected among themselves than with the other constituents of the compound, or when they play the part of a compound radical, they are separated from the rest by commas, inclosed in a parenthesis, or a single symbol (Cy), as in the case of cyanogen ($C_2N_2$), is substituted for the group. Thus the following equation may be written—

$$Hg, C_2N_2 = Hg + 2\ CN \quad \text{or}$$
$$Hg\ (Cy_2) = Hg + 2\ Cy$$

The plus-sign (+) is also used to separate atomic groups.

**288. Chemical Equations.**—The results of chemical reaction are represented in the form of equations, which depend upon the principle that nothing is lost in the course of transformation. The bodies to be acted upon are placed at the left, and connected by the sign of addition +. The sign of equality = signifies that the products of the change which are written at the right equal the bodies at the left. The equation also implies that the molecules at the left side are convertible into those written upon the right. The equation $CaO + H_2O = CaO_2H_2$ represents simply that, if a molecule of lime be added to a molecule of water, the product formed will be a molecule of calcic hydrate or slacked lime.

# PART III.

# DESCRIPTIVE CHEMISTRY.

## DIVISION I.—PERISSAD ELEMENTS.

## CHAPTER XI.

### HYDROGEN.

Symbol, H. Atomic Weight, 1; Quantivalence, 1; Specific Gravity, 1; Molecular Weight, 2; Molecular Volume, 2.

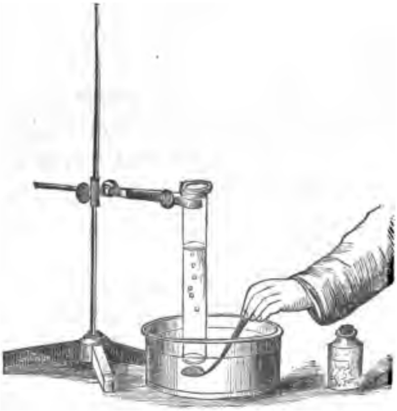
**289. Its Position.**—In entering upon the description of the properties of chemical substances we begin with hydrogen, which is taken as the unit, or starting-point of the established system. It is an element of great importance in Nature, as well as in chemical theory; and is so individual in its character that it is difficult to classify with other elements, and so will be most conveniently considered at first and by itself.

**290. History.**—It was known by Paracelsus, in the sixteenth century, that when iron is dissolved in sulphuric acid an air is given off; this air was shown by Boyle, in 1672, to be inflammable; and by Lemery, in 1700, to have detonating properties. But the first exact experiments upon it were made by Cavendish in 1766, and it was called by him *inflammable air*. In 1781 Cavendish made the great discovery that water is the sole product of the combustion of this gas, and Lavoisier therefore gave it the name *hydrogen*, from two Greek words signifying water-generator.

**291. Occurrence in Nature.**—Hydrogen is universally diffused, and takes an active and varied share in the chemical operations of Nature. Existing in water, which is decomposed with facility, it pervades the crust of the earth, and ministers to the transformation of minerals; while, as a large constituent of all living things, its changes contribute to carry on the processes of life. It is present in nearly all kinds of compounds, combined with other elements. It forms one-ninth of the weight of water, and the body which contains the largest proportion of it is hydric carbide (marsh-gas), of which it forms one-fourth. It was formerly held that hydrogen does not exist free in Nature; but it is now found uncombined in volcanic gases, in meteoric stones, and, as we have seen, exists free in immense masses in the atmospheres of the sun and stars.

**292. Preparation.**—Hydrogen is generally obtained by decomposing water and setting the gas free. It is usually collected in inverted jars filled with water, as represented in Fig. 123. If a bit of the metal sodium in a spoon be placed under the mouth of such a jar, it decomposes the water rapidly, combining with its oxygen, and setting free the hydrogen, which rises in bubbles and displaces the water in the jar. Steam passed through a red-hot gun-barrel is decomposed by the iron,

FIG. 123.

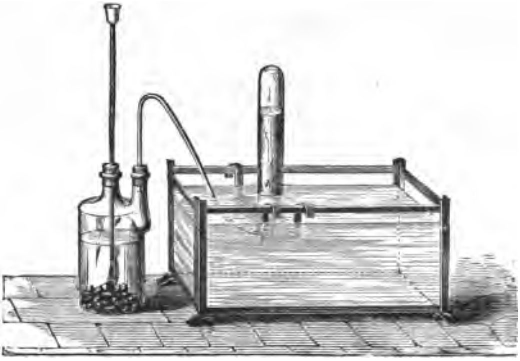


Liberation of Hydrogen by Sodium.

which combines with the oxygen and sets the hydrogen free. A current of electricity passed through water severs its constituents, and liberates both oxygen and hydrogen, when they may be collected separately (141).

**293. By the Use of Zinc.**—Hydrogen is commonly prepared, however, by the action of dilute hydric sulphate (sulphuric acid) upon bits of zinc. The zinc is placed in a two-necked bottle (Fig. 124) and covered with water. The tube, with a funnel at top, admits the acid, when the action begins at once, the gas bubbles up freely and passes off through the curved tube, which delivers it under the mouth of an inverted jar, as before, but which now rests upon a support below the surface of the water. A vessel for the collection of gases, in this way, is called a *pneumatic trough.* It is usually a tank (represented in the cut as having glass sides), in which jars are filled with water, inverted, and then slid upon the shelf, the water being supported above its level by atmospheric pressure. When the jars are filled with gas they may be slipped off, mouth downward, into shallow vessels containing a little water, and kept for use. In the foregoing reaction the hydric

FIG. 124.



Preparation of Hydrogen.

sulphate is decomposed by the zinc, while the hydrogen is liberated, and zinc sulphate formed. The changes are represented by the following equation:

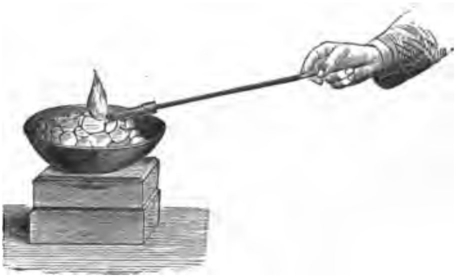
$$\underset{\text{Sulphuric Acid.}}{H_2{=}SO_4} + \underset{\text{Zinc.}}{Zn.} = \underset{\text{Zinc Sulphate.}}{Zn.{=}SO_4} + \underset{\text{Hydrogen Gas.}}{H\text{-}H.}$$

**294. Chemical Properties.**—As usually prepared, hydrogen has a disagreeable odor, arising from the impurities of the materials employed; but pure hydrogen is a transparent, tasteless, inodorous gas, very slightly soluble in water, inflammable, and having great chemical activity. It is an essential constituent of bases and acids, the latter being properly salts of hydrogen. It unites with metals and organic radicles, forming compounds called *hydrides.* It does not support respiration, and animals immersed in it soon die. When mixed with air it may be breathed without immediate injury, but from its tenuity it imparts a squeaking tone to the voice. All attempts to liquefy it, either by pressure or cold, have failed. In the gaseous state hydrogen is combined with itself, forming the molecule, H-H.

**295. Its Lightness.**—Hydrogen is the lightest of all known substances, being 14½ times lighter than air, 16 times lighter than oxygen, and 11,000 times lighter than water. Hence it may be carried in jars with the open mouth downward, and transferred to other vessels by pouring upward. Soap-bubbles filled with it rise to the ceiling, and it gives the greatest levity to balloons; though they are usually inflated with a hydrocarbon gas, the lightness of which is due to the hydrogen it contains. Owing to the fineness of its molecules it will escape through the joints of apparatus that are perfectly tight to other gases; and a stream of it directed against one side of a piece of gold-leaf passes through so rapidly that it may be ignited on the other side.

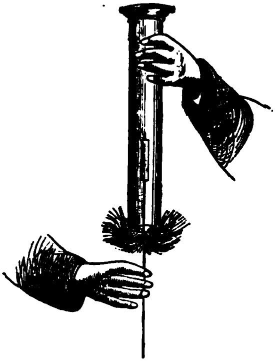
**296. Inflammability and Explosiveness.**—If a jet of hydrogen in the air is ignited it burns with a pale-blue flame, which brightens as the pressure of the air is increased. But, though the light emitted is small, the heat produced is intense. The result of the combustion is pure water. If hydrogen and oxygen gases are mixed in the proportion to form water, that is, two volumes of H to one of O, and the mixture is then ignited by an electric spark, or the application of fire, the gases combine explosively with a sharp report. The same effect, though less intense, is produced by mingling five volumes of air with two of hydrogen. Soap-bubbles blown with such a mixture detonate when ignited. (Fig. 125.) In experimenting with hydrogen, it is therefore necessary to guard against the accidental intermixture of air with the gas. The lightness, explosiveness, and inflammability of hydrogen, and that it cannot itself sustain combustion, may be all shown by a very simple experiment illustrated by Fig. 126. If a jar of hydrogen be held mouth downward, and a lighted taper be introduced, it is extinguished, while the gases are ignited and burn at the mouth of the jar. If, now, the jar is inverted, the escaping hy-

FIG. 125.



Exploding Soap-Bubbles.

FIG. 126.



Experiment illustrating the Properties of Hydrogen.

drogen unites with air, and there is a slight explosion.

**297. Condensation of Hydrogen.**—But hydrogen and oxygen may be ignited without the application of fire. The metal platinum can be converted into a kind of powdery condition known as platinum-sponge. If, now, a jet of hydrogen be directed against a little ball of this sponge, it instantly becomes red-hot, and remains so as long as the current lasts. Döbereiner's lamp depends upon this principle. The theory of it is that oxygen is condensed within the fine pores of the metal, and the hydrogen also being condensed by it, their molecules are brought within combining range, and union results. But the porous condition of the metal is not essential to this action. Clean strips of platinum will condense the gases upon their surface sufficiently to cause rapid combination.

**298. Occlusion of Hydrogen.**—Red-hot platinum, palladium, and iron, are freely permeable by hydrogen, and when cold are capable of retaining considerable portions of the gas. These metals are also capable of absorbing and retaining more or less of hydrogen when it is presented to them in a nascent state. Graham, who terms this effect *occlusion*, has shown that palladium takes up more than 900 times its volume of hydrogen, and that the product is a white metallic solid. Graham regarded this compound as an alloy, consisting of palladium and solidified hydrogen, which he believed to be a metal, and called it *hydrogenium*. Hydrogen in combination is replaced by metals, and undoubtedly has strong analogies with them; but it is also replaced by chlorine, and its analogies with the chlorous elements are as numerous, as strongly marked, and as important, as with those of the basilous class.

In the earlier stages of the science oxygen held the leading place; but, as we have seen, hydrogen has usurped its office as acid-former, and now occupies by far the most important chemical position.

# CHAPTER XII.

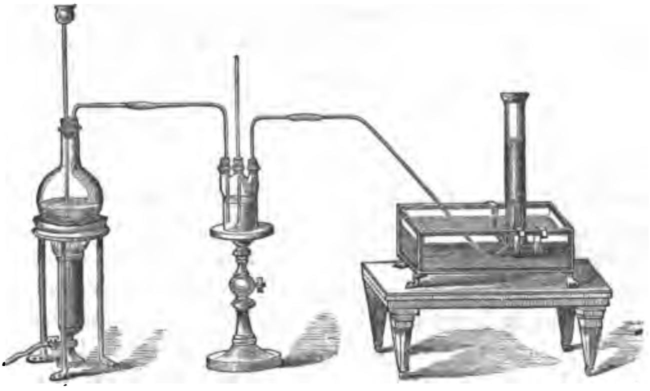
## THE CHLORINE GROUP.—CHLORINE, FLUORINE, BROMINE, IODINE.

### § 1. *Chlorine and its Compounds.*

**Chlorine.**—Symbol, Cl. Atomic Weight, 35.5; Quantivalence, I., III., V. and VII.; Molecular Weight, 71; Molecular Volume, 2; Specific Gravity, 2.47.

**299. History.**—Chlorine was discovered by Scheele, in 1774, but was long regarded as a compound. In 1810 Davy established its elementary character, and gave it the name it bears, from the Greek *chloros*, yellowish green. It is never found free in Nature, but exists abundantly in the mineral world, chiefly in combination with the metal sodium, as common salt.

Fig. 127.



Preparation of Chlorine.

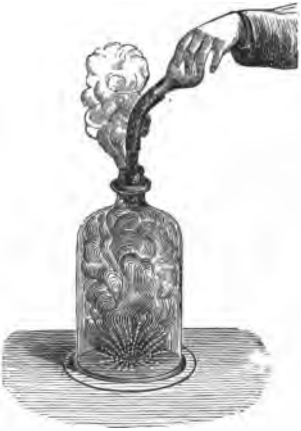
**300. Preparation.**—Scheele's method of obtaining chlorine by the action of hydric chloride on manganic dioxide is still generally adopted. The manganic dioxide is placed in a flask provided with a safety-tube for pouring in the acid, and one for the delivery of the gas. To the delivery-tube is attached an intermediate bottle containing sulphuric acid, which is a powerful absorbent of water, and which dries the gas by separating its adhering moisture. From this bottle it passes through a long glass tube to the receiver (Fig. 127). A little acid is first poured in and well shaken up with the manganese, in order to wet every portion of it; more acid is then added, and a gentle heat applied, when the gas is given off copiously. It may be collected by displacement, or over warm water in a pneumatic trough. The chlorine, being heavier than air, collects at the bottom of the vessel, and the greenish color of the gas will indicate when the vessel is filled. The reaction may be thus expressed:

$$MnO_2 + (HCl)_4 = MnCl_2 + (H_2O)_2 + Cl_2.$$

Chlorine may also be prepared from common salt by the aid of sulphuric acid and manganic dioxide.

**301. Properties.**—Chlorine is one of the most energetic of bodies, surpassing even oxygen under some circumstances. At ordinary temperatures chlorine (Cl-Cl) is a yellowish-green gas, but by a pressure equal to four atmospheres, or by exposure to a cold of —40° C., it may be condensed to a transparent, yellow liquid, of 1.38 specific gravity, which remains unfrozen at —110° C. The gas has a peculiar, suffocating odor, and if inhaled, even when considerably diluted, produces distressing irritation of the throat and lungs. When respired, however, in very minute quantities, it is not only harmless, but is said to be beneficial to those affected with pulmonary disease. Chlorine maintains combustion; many bodies burn in it readily and some take fire in it spontaneously, such as phosphorus, finely-powdered antimony (Fig. 128), zinc, and arsenic. Many organic compounds, rich in hydrogen, are decomposed by it so rapidly as often to burst into flame. A piece of paper saturated with oil of turpentine and plunged into a vessel filled with chlorine (Fig. 129), emits a dense, black smoke, and usually ignites, from the rapid decomposition of the turpentine. Hydric chloride is formed and carbon deposited.

FIG. 128.

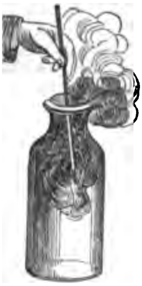


Combustion of Antimony in Chlorine.

Cold water absorbs about two and a half times its own bulk of chlorine, the solution acquiring the color, taste, and smell of the gas. If this solution is cooled down to 0° C., a definite crystalline hydrate of chlorine is formed, having the formula $Cl^5 + H^2O$. Liquid chlorine may be readily obtained from these crystals by hermetically sealing them in a curved tube, and applying a gentle heat. This liberates the chlorine, which, pressing upon itself, assumes the condition of a liquid. It may be distinguished from the water present by its yellow color. Chlorine solution readily dissolves gold. Light decomposes chlorine-water, giving rise to hydric-chloride solution and free oxygen; hence it is necessary that it be kept in bottles protected by some opaque covering.

**302. Uses.**—One of the most valuable qualities of chlorine is its bleaching power. Chlorine-water, or the moist gas, immediately discharges the colors of ordinary fabrics, indigo, common ink, etc. It is principally used in bleaching cotton cloth and rags of which paper is to be made. Not only does chlorine destroy the coloring-matter by uniting with its hydrogen, but it decomposes the associated water, setting free oxygen, which, in its nascent state, acts powerfully to oxidate and destroy the coloring particles. Dry chlorine will not bleach; it acts only through the agency of water. But it is so powerful that, if the bleaching solution is not quickly removed, it corrodes and weakens the fabric. It has no action upon carbon, and therefore does not bleach printer's ink. Argentic nitrate (lunar caustic) added to a solution containing chlorine, or a soluble chloride, gives a white precipitate of argentic chloride, AgCl, which on exposure to light changes first to violet, and then to black. Argentic nitrate is the test for chlorine. This element is largely used in the preparation of chloride of lime, in which form it is made available as a bleaching agent.

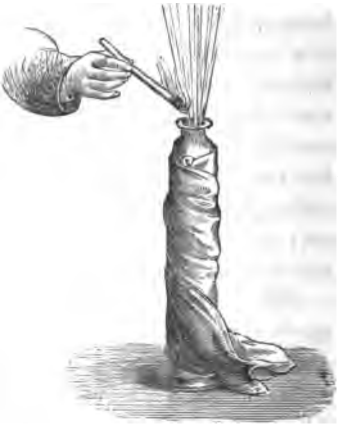
FIG. 129.



Combustion of Oil of Turpentine in Chlorine.

**303. Hydric Chloride,** HCl (*Muriatic Acid*).—This is the only compound of chlorine and hydrogen known. It was discovered by Priestley in 1772. It occurs in Nature among the gaseous products of volcanic eruptions. A mixture of chlorine and hydrogen gases, when exposed to direct sunlight, is converted, with violent explosion, into hydric chloride. Each of the gases also burns freely in an atmosphere of the other. If a jar be filled one half with hydrogen, and the other half with chlorine, and the gases ignited at the mouth, an explosion takes place; and white fumes of

FIG. 130.



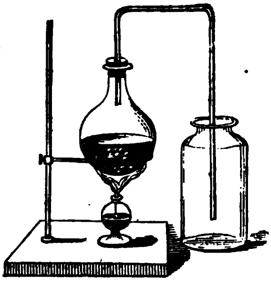
Direct Union of Chlorine and Hydrogen.

hydric chloride are formed. A towel should be wrapped around the jar to prevent the pieces from scattering in case of explosion (Fig. 130). Hydric chloride is generally prepared by the action of sulphuric acid on sodic chloride (common salt). The reaction is expressed by the equation:

$$2\ (NaCl) + H_2SO_4 = + Na_2SO_4 + 2\ (HCl).$$

As the gas is greedily absorbed by water, it must be collected over mercury, or by displacement. Fig. 131 shows a convenient arrangement for its preparation.

FIG. 131.



Preparation of Hydric Chloride.

**304. Properties and Uses.**—Hydric chloride is a colorless, pungent, acid gas, irrespirable, very irritating to the eyes, and extinguishes flame. It is somewhat heavier than air, having a specific gravity of 1.24. Under a pressure of 40 atmospheres at —10° C., or of 2 atmospheres at —70° C., it condenses into a colorless liquid of 1.27 specific gravity, which has never been frozen. Hydric chloride is exceedingly soluble in water, which, at 4° C., absorbs 480 times its volume of the gas. This solution is much used in the laboratory as a chemical reagent.

**305. Compounds of Chlorine and Oxygen.**—The compounds of chlorine and oxygen are unstable, and most of them explosive. Chlorine may act as a monad, a triad, a pentad, or a heptad, and its compounds with oxygen, together with the corresponding acids, are as follows:

| | |
|---|---|
| Chloric monoxide, $Cl^{I}_2O$ | Hypochlorous acid, $HCl^{I}O$. |
| Chloric trioxide, $Cl^{III}_2O_3$ | Hydric chlorate, $HCl^{III}O_3$. |
| Chloric tetroxide, $Cl^{V}_2O_4$ | Hydric perchlorate, $HCl^{V}O_4$. |

**306. Chloric Monoxide,** $Cl_2O$.—This compound, also known as hypochlorous oxide, may be obtained by passing dry chlorine through a tube filled with mercuric oxide. A portion of the chlorine takes the place of the oxygen, forming mercuric chloride, while another portion unites with the oxygen, at the moment of its liberation, forming chloric monoxide. As a gas, its color is a shade darker than that of chlorine, and it has a similar pungent odor. It is a powerful oxidizing agent, and possesses remarkably strong bleaching power.

**307. Chloric Tetroxide,** $Cl_2O_4$.—When potassic chlorate, $KClO_6$, is made into a paste with sulphuric acid and cooled, and this paste is cautiously heated in a glass retort, over a water-bath, a deep-yellow gas is evolved, which can only be collected by displacement. Chloric tetroxide has a powerful odor, and, if heated, explodes with great violence. It may be liquefied by cold. It is absorbed by water, the solution possessing strong bleaching properties.

**308. Chloric Acid, Hydric Chlorate,** $HClO_3$.—This compound may be obtained by decomposing a solution of potassic chlorate with a solution of hydro-fluosilicic acid, the products being an insoluble potassic fluosilicate, and a dilute solution of chloric acid, which, by cautious evaporation at a low temperature, may be concentrated to the consistence of a syrup. It is a very unstable compound, being easily decomposed, especially by organic matter, which it sometimes ignites.

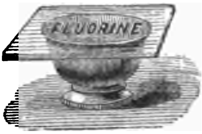
## § 2. *Fluorine and its Compounds.*

FLUORINE.—Symbol, F. Atomic Weight, 19; Quantivalence, I.; Molecular Weight, 38 (?); Molecular Volume, 2 (?).

**309. History.**—This substance does not occur in Nature, uncombined, and very little is known in regard to it. Its most frequent compound is calcic fluoride (fluor-spar), and from this it receives its name. In consequence of its great affinity for other substances, it has never been satisfactorily isolated.

**310. Hydric Fluoride,** HF.—Hydric fluoride is produced when a metallic fluoride (as fluor-spar) is acted upon by hydric sulphate with the application of heat. Hydric fluoride attacks and corrodes glass, and the process must, therefore, be conducted in vessels of lead or platinum. As thus obtained it is a colorless gas, which does not condense to a liquid at −12° C. On account of its strong affinity for water, it fumes in the air, and, if inhaled, produces intense irritation of the lungs. The distinguishing characteristic of hydric fluoride is its corrosive action on glass. This may be shown by placing some powdered calcic fluoride, made into a paste with sulphuric acid, in a leaden cup (Fig. 132), and covering it with a plate of glass, previously smeared on one side with beeswax, through which characters have been traced with a fine-pointed instrument. The waxed side is placed next the mixture, and a gentle heat applied to the cup. After the lapse of half an hour, on removing the glass, and cleaning off the wax with the aid of a little oil of turpentine, the letters will be found corroded into the glass. The hydric fluoride has reacted upon and decomposed the silica of the glass at the exposed points. This quality is taken advantage of to etch the labels on glass bottles that are to be used in laboratories and drug-shops, where corrosive substances abound.

Fig. 132.



Action of Fluorine.

## § 3. *Bromine.*

Symbol, Br. Atomic Weight, 80; Quantivalence, I., V., and VII.; Molecular Weight, 160; Molecular Volume, 2; Specific Gravity, 3.187.

**311. History and Preparation.**—This substance was first obtained by a French chemist in 1826. The name bromine is derived from the Greek *bromos*, "stench." It is not found native. After the extraction of the crystallizable salts from the sea-water, there is left a solution of the more soluble salts, called the mother-liquor or bittern. This bittern is rich in bromides, and, by heating this with manganic dioxide and hydric sulphate, chlorine is liberated from the decomposed chlorides. The chlorine, in its turn, sets free the bromine from the bromides, and the vapors are collected in a cooled receiver, where they condense into a liquid.

**312. Properties and Uses.**—Bromine, at ordinary temperatures, is a liquid of a deep brownish-red color. It has a peculiar, irritating, disagreeable odor. At −22° C. it solidifies to a hard, brittle, laminated mass, having a dark lead-gray color and semi-metallic lustre. At about 122° (50° C.) it boils, forming red vapors. It dissolves sparingly in water, more readily in alcohol, and in all proportions in ether. It is an active chemical agent, and a violent poison. Bromine is used in photography, and occasionally as a disinfectant.

## § 4. *Iodine.*

Symbol, I. Atomic Weight, 127; Quantivalence, I., III., V., and VII.; Molecular Weight, 254; Molecular Volume, 2; Specific Gravity, 4.94.

**313. History.**—Iodine was discovered in 1811, in products of decomposition obtained from the mother-liquor, which remains when the ashes of sea-weed, known as "kelp," are leached, and allowed to crystallize. The name iodine is derived from the Greek *ion*, "violet," and refers to the color of its vapor. It is not found native. The preparation is similar to that of bromine. The mother-liquors are distilled with manganic dioxide and hydric sulphate, and the vapors condensed.

**314. Properties and Uses.**—Iodine is a grayish-black solid of metallic lustre, and crystallizing in forms of the trimetric system. It melts at 225° (107° C.), and boils at 356° (180° C.), rising in dense, beautiful, deep-violet vapor, which is 8.72 times heavier than air. Iodine volatilizes even at ordinary temperatures, diffusing an odor somewhat similar to that of chlorine, though easily distinguished from it. It is sparingly soluble in water, more easily in alcohol and ether, or aqueous solutions of iodides. Iodine colors starch-paste a beautiful deep-blue, this reaction constituting the most delicate test of its presence. It stains the skin yellow, but is not so corrosively poisonous as chlorine or bromine. It is a non-conductor of electricity.

Iodine is extensively used in photography, in the preparation of iodides, as a chemical reagent, and in medicine. A dark-brown solution of iodine in alcohol (containing also potassic iodide) is familiarly known as tincture of iodine, and much used as a liniment.

**315. Hydric Bromide**, $HBr$., and **Hydric Iodide**, $HI$.—These bodies are produced by the action of dilute sulphuric acid on bromides and iodides, but the compounds, especially the hydric iodide, are liable, under these circumstances, to be further decomposed. By heating bromine or iodine with hydrogen, these bodies are also formed, but for practical purposes they are best prepared by allowing bromine and iodine to react upon phosphorus in the presence of water. The properties of hydric bromide and iodide are similar to those of hydric chloride.

**316. The Halogen Group.**—The elements fluorine, chlorine, bromine, and iodine, constitute a well-marked chemical series, exhibiting a regular progression of properties. Chlorine is a gas, bromine a liquid, and iodine a solid, at ordinary temperatures. Their molecules are all diatomic. Chemically they are highly active bodies, and, when brought in contact with certain metals, readily give rise to a class of compounds, of which common salt is the type. Hence they have been named halogens, from Greek words meaning salt-formers. The hydrogen compounds of these elements, represented by HF, HCl, HBr, and HI, also form a well-marked series. At ordinary temperatures they are all colorless gases, of pungent, suffocating odor, and powerful acid properties, hydric fluoride being chemically the most, and hydric iodide the least, active.

# CHAPTER XIII.

## THE SODIUM GROUP—SODIUM, POTASSIUM, LITHIUM, RUBIDIUM, CÆSIUM.

### § 1. *Sodium and its Compounds.*

SODIUM.—Symbol, Na. (Natrium). Atomic Weight, 23; Quantivalence, I. and III.; Specific Gravity, 0.98.

**317. Preparation and Properties.**—Metallic sodium, Na-Na, was first obtained by Davy, in 1807, by decomposing sodic hydrate (NaHO) by the electric current. Sodium does not occur native, but is now manufactured on a large scale, by distilling a mixture of sodic carbonate and charcoal at a high temperature. Sodium, when freshly cut, presents a silvery appearance, and, if cast upon hot water, bursts into a beautiful yellow flame, and is converted into sodic oxide, or soda (Fig. 133). Sodium is a very abundant metal, constituting more than two-fifths of common salt, and existing as a large ingredient of rocks and soils.

FIG. 133.

Combustion of Sodium.

**318. Sodic Chloride** (NaCl) (*Common Salt*) may be formed by the direct union of its constituents, and is obtained commercially, either by mining it in the form of rock-salt, or by evaporating the water of salt-springs. Sea-water contains in every gallon about four ounces of salt. Estimating the ocean at an average depth of two miles (Lyell), the salt it holds in solution would, if separated, form a solid stratum 140 feet thick. Saline springs in various localities in this country yield enormous quantities of salt by the process of evaporation. The springs in the State of New York, alone, furnish an annual supply of about 6,000,000 bushels. As a solid it occurs in extensive beds in various localities in Europe. The celebrated bed at Wielitzka, Poland, is said to be 500 miles long, 20 miles broad, and 1,200 feet thick, containing salt enough to supply the entire world for thousands of years.

**319.** Salt exists in small quantities in plants, and sometimes promotes their growth by being applied to the soil. It is also an ingredient of animal bodies, being contained in the blood. It forms an important constituent of the food of both man and beast, an adult consuming about five ounces per week.—(Pereira.)

Common salt is readily soluble alike in hot or cold water, and usually crystallizes in cubes. A peculiar-shaped crystal, or aggregation of crystals, is often formed when the salt is allowed to crystallize from concentrated solutions. A small cube is first formed which sinks so as to

Fig. 134.

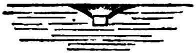


Fig. 135.

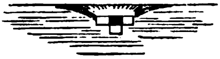


Fig. 136.

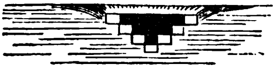


Fig. 137.

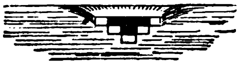
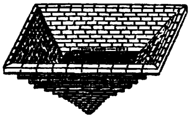


Fig. 138.



Crystallization of Common Salt.

bring its upper surface on a level, or a little below the surface of the water (Fig. 134). Other cubes form on this, and, as the mass sinks, others still are deposited, each layer being attached to the upper and outer edge of the layer next below, until the hopper-like form shown in Fig. 138 is obtained.

**320. Uses.**—Salt is used for packing and preserving meat, as it prevents putrefaction, by absorbing water from the flesh. It is also used as a source of sodium in the manufacture of sodic hydrate, and as a source of chlorine in the production of hydric chloride. It fuses at a red heat, and hence is used for glazing stone-ware, earthenware, etc.

**321. Sodic Carbonate** ($Na_2CO_3$).—Sodic compounds are supposed to perform the same function in the economy of marine plants that the corresponding potassium compounds perform in land plants, and sodic carbonate was formerly obtained by leaching the ashes of the former. It is now manufactured almost entirely from common salt, by Leblanc's process. This consists, first, in treating sodic chloride with sulphuric acid, forming crude sodic sulphate, or *salt-cake*, and hydric chloride. The next step in the process is to convert sodic sulphate into a crude carbonate. This is effected by heating the salt-cake with finely-ground coal and calcic carbonate (chalk) in a reverberatory furnace, constructed for the purpose. After the mass is thoroughly fused it is raked out into wooden troughs, and allowed to cool, forming *ball-soda* or *black-ash*.

In this operation, calcic sulphide and carbonic monoxide are also formed, the reaction taking place according to the equation:

$$Na_2SO_4 + Ca'' CO_3 + 4C = Na_2CO_3 + Ca'' S + 4CO.$$

The sodic carbonate being the only constituent of the black-ash that is readily soluble, is separated by leaching with warm water; and lastly, the solution is evaporated to dryness, yielding the soda ash or crude carbonate of commerce. When a hot, filtered solution of this is allowed to cool quietly, large transparent crystals of a decahydrated salt ($Na_2CO_3 + 10H_2O$) are obtained. These are known as sal-soda. Sodic carbonate is extensively used in the manufacture of soap and glass, being both cheaper and purer than the ordinary potash. It is also used as a detergent, both in calico-printing and in the laundry.

**322. Hydro-Sodic Carbonate** ($NaHCO_3$).—This is produced by passing carbonic dioxide through a solution of sodic carbonate. It is used under the name of saleratus, forms part of effervescing soda-powders, and is used in bread making.

**323. Sodic Hydrate,** $NaHO$ (*Caustic Soda*).—This compound is obtained by decomposing a solution of sodic carbonate ($Na_2CO_3+H_2O$) with calcic hydrate (slacked lime, $CaH_2O_2$) at the boiling temperature, allowing the calcic carbonate formed to subside, drawing off the clear solution of sodic hydrate, and concentrating by evaporation. Thus prepared it is a white, opaque, brittle substance, which melts below red heat, and volatilizes at higher temperatures. It is also formed by the action of sodium upon water.

**324. Sodic Sulphate** ($Na_2SO_4+10H_2O$) (*Glauber's Salt*).—This well-known salt may be formed by adding sulphuric acid to soda, and is chiefly procured in the manufacture of hydric chloride. It has a bitter, saline taste, and loses its water of crystallization on exposure to the air.

**325. Sodic Nitrate,** $NaNO_3$ (*Soda-Saltpetre*).—Procured native from parts of Brazil and Chili. Attempts have been made to substitute this salt for nitrate of potash in the manufacture of gunpowder, but its tendency to attract moisture from the air has rendered it impracticable. Nitric acid is obtained from sodic nitrate, and it has been somewhat used as a fertilizer.

## § 2. *Potassium and its Compounds.*

**Potassium.**—Symbol, K. (Kalium). Atomic Weight, 39; Quantivalence, I., III., and V.; Specific Gravity, 0.86.

**326. History and Occurrence.**—This metal was discovered by Sir Humphry Davy in 1807. He first obtained it by subjecting moistened potash to the action of a powerful voltaic battery; the positive pole gave off oxygen, and metallic globules of pure potassium appeared at the negative pole. It is found abundantly in Nature, but never uncombined. It is obtained by the action of charcoal upon potassic carbonate at a very high temperature. The potassic carbonate is decomposed with liberation of *potassium*, carbonic monoxide, and small quantities of other compounds but little known. Leaving these out of view, the reaction may be represented by the equation:

$$K_2CO_3 + 2C = 3CO + K_2.$$

**327. Metallic Potassium** (*Molecule*) (K-K), at common temperatures, is a silver-white metal, and so soft that it may be moulded like wax. If thrown upon the surface of water, instant decomposition takes place (Fig. 139), potassic oxide being at first formed. The liberated hydrogen, together with a small quantity of volatilized metal, is ignited by the heat evolved during the decomposition, and burns with a beautiful lilac flame as the globule floats about on the surface of the liquid. At the close of this reaction a second change ensues: the potassic oxide, which had been kept above the surface of the water, coming in contact with the liquid, gives rise to the formation of potassic hydrate, which becomes red-hot, and scatters with a violent explosion. Potassium decomposes nearly all compounds

Fig. 139.

Combustion of Potassium.

containing oxygen, if brought in contact with them at high temperatures, and many even at ordinary temperatures. Hence, to preserve it pure, it is kept in *naphtha*, a liquid containing no oxygen.

**328. Potassic Monoxide** ($K_2O$).—This compound is obtained by exposing metallic potassium to perfectly dry air, free from carbonic dioxide, at ordinary temperatures. It is a white solid, which melts at a red heat, and volatilizes at higher temperatures. It is very deliquescent; brought in contact with water it becomes incandescent, potassic hydrate being produced.

**329. Potassic Hydrate** ($KHO$) (*Caustic Potash*).—The method of obtaining this important substance is similar to that of obtaining caustic soda. The solution of potassic hydrate, after being boiled until the temperature of the liquid is near a red heat, flows without ebullition, and may be run into moulds, solidifying on cooling to a white, hard, brittle substance, which melts, below redness, to an oily liquid, and volatilizes at a full red heat in white, pungent vapors. Potassic hydrate dissolves freely in water, with great evolution of heat. It has a peculiar nauseous odor, and acrid taste. It decomposes acids with formation of corresponding potassic salts and elimination of water, changes vegetable yellows to brown, restores the blues discharged by acids, and decomposes animal and vegetable substances, whether living or dead. It is used in medicine to cauterize and cleanse ulcers and foul sores; hence its name, *caustic potash*. If a solution of potash be shaken in a bottle with any fixed oil, the two unite, forming a *soap*. This accounts for the soft, greasy feel it has when touched by the fingers, as it decomposes the skin and forms a soap with its oily elements. When taken into the system, potash acts as a powerfully corrosive poison. Its active chemical character renders it an indispensable reagent in the laboratory.

**330. Potassic Chloride** ($KCl$) is known as the mineral sylvite, and is isomorphous with $NaCl$. Potassic iodide

(KI) may be formed by adding iodine to a solution of potash, and gently warming until the solution assumes a brown tint. It is a very soluble, white solid, which crystallizes in cubes, and is much used in medicine.

**331. Potassic Carbonate** ($K_2CO_3$).—Potassic salts of various kinds exist in the juices of plants. By the combustion of the plants, most of these are decomposed with the formation of potassic carbonate, which may be obtained from their ashes. This is a highly alkaline, deliquescent salt, and is used largely in the manufacture of soap and glass, in preparing caustic potash, etc. It is also an important reagent in the laboratory, and a most valuable fertilizer. This salt rarely forms less than 20 per cent., and sometimes more than 50 per cent., of the weight of wood-ashes. The ashes of different plants, and even different parts of the same plant, yield it in varying quantities. Wood ashes furnish the principal source of the potassic carbonate of commerce, from which it is obtained by leaching them and boiling the solution to dryness in iron pots. The residue is called *potashes*, and these, when calcined, afford the impure carbonate known as *pearlash*. Potash, or pearlash, therefore represents the readily soluble portion of wood-ashes, and consists chiefly of potassic carbonate with small amounts of sodic carbonate and common salt.

**332. Hydro-Potassic Carbonate** ($KHCO_3$).—This is formed by passing carbonic dioxide through a strong solution of potassic carbonate. It is employed as a source of potassium in the formation of many of its other compounds, and is also used for making effervescing draughts, by adding citric or tartaric acid to its solution.

**333. Potassic Nitrate** ($KNO_3$) (*Nitre*, *Saltpetre*).—This salt occurs as a native product in the earth of various districts in the East Indies, and is separated therefrom by leaching the soil, and allowing the nitre to crystallize. It is artificially formed by heaping up organic matter with lime, ashes, and soil, and keeping the mass well moistened with urine for a period of two or three years, when the heap is lixiviated and the salt crystallized out. Besides these sources, nitre occurs in the sap of certain plants, such as the sunflower, tobacco-plant, etc. Nitre dissolves in about three times its weight of cold and one-third its weight of boiling water. When thrown upon burning charcoal it is decomposed and deflagrates violently. Paper dipped in a solution of sodic nitrate, and dried, forms what is known as *touch-paper*. When ignited, it burns slowly and steadily until consumed; hence its use in lighting trains of gunpowder, fireworks, etc. Nitre has a cooling, saline taste and strong antiseptic powers. Owing to the latter quality it is used extensively in packing meat, to which it imparts a ruddy color. It is chiefly consumed, however, in the manufacture of gunpowder.

**334. Gunpowder** is an intimate mechanical mixture of about 1 part nitre, 1 part sulphur, and 3 parts charcoal. These proportions, however, vary somewhat in different countries, as well as in different sorts of powder. More charcoal adds to its power, but also causes it to attract moisture from the air, which of course injures its quality. For blasting rocks, where a sustained force, rather than an instantaneous one, is required, the powder contains more sulphur, and is even then often mixed with sawdust to retard the explosion. The nitre, sulphur, and charcoal, having been ground and sifted separately, are thoroughly mixed and then made into a thick paste with water. This is ground for some hours under edge stones, after which it is subjected to immense pressure between gun-metal plates, forming what is known as *press-cake*. These cakes are then submitted to the action of toothed rollers, whereby the granulation of the powder is effected. The grains thus formed are sorted by means of a series of sieves, and thoroughly dried at a steam heat. The last operation, that of polishing, is accomplished in revolving barrels, after which the powder is ready for market. The heavier the powder, the greater is its explosive power. Good powder should resist pressure between the fingers, giving no dust when rubbed, and have a slightly glossy aspect. The explosive power of gunpowder is due to a sudden formation of a large volume of nitrogen and carbonic dioxide; one volume of the powder giving about 1,800 volumes of vapor. *Fireworks* contain nitre as a chief ingredient, mixed with charcoal, sulphur, ground gunpowder, and various coloring substances.

**335. Potassic Sulphate** ($K_2SO_4$) is obtained in the manufacture of hydric nitrate, and is of limited use in the arts. Potassic chlorate ($KClO_3$) may be formed by passing chlorine gas through a solution of potassic carbonate ($K_2CO_3$). Potassic chlorate is soluble in water, has a taste resembling that of nitre, melts at about 700°, and, if heated above that temperature, decomposes with formation of potassic chloride and perchlorate, and oxygen gas. It is used in the manufacture of lucifer matches, in certain operations of calico-printing, and as a source of oxygen.

**336. Sodic and Potassic Silicates.**—If 8 or 10 parts of sodic or potassic carbonate are mixed with 12 or 15 parts of sand and 1 of charcoal, on being heated they melt, and form a mass resembling ordinary glass; but it entirely dissolves in hot water. This is known as *soluble glass*, and when applied to wood and other substances answers the protective purpose of a varnish or paint.

**337. Soap.**—When caustic potash, or soda, acts upon certain organic acid radicles, chiefly oleine and stearine, which are present in fats and oils, the resulting salts are termed *soaps*, and the process by which they are produced is called *saponification.* The consistence of soap depends chiefly upon its alkali. Hard soaps are made of soda, or a mixture of soda and potash, while in soft soaps potash alone is used, the soaps made with this base being deliquescent and consequently attracting water, which renders the soap liquid. The quality of hardness is due to the consistence of the oil or fat. The compounds containing a large proportion of stearin and palmitin, like tallow, form hard soaps, while those in which olein predominates, as the soft fats and oils, produce soap of softer consistence. The glycerin which is retained in soft soap also adds to its fluidity. Soap has a powerful affinity for water, and may retain from 50 to 60 per cent. of it and still continue solid; hence dealers frequently keep it in damp places where it will absorb moisture. It is soluble in fresh water, but, with the exception of cocoa-soap, is insoluble in salt-water.

**338. Mode in which Soap acts in Cleansing.**—As water, having no affinity for oily substances, will not dissolve them, of course it cannot alone remove them from surfaces to which they may adhere. The oily matters which are constantly exuding from the glands of the skin, uniting with the outer dust, form a film over the body. The alkali of the soap acts upon the oil during ablution, partially saponifies it, and renders the unctuous compound freely miscible with water, so as to be easily removed. The cuticle or outer layer of the skin is chiefly composed of albumen, which is soluble in the alkalies. The alkali of the soap, therefore, dissolves off a portion of the cuticle with the dirt; every washing with soap thus removing the old face of the scarf-skin and leaving a new one in its place. The action of soap in cleansing textile fabrics is of a similar nature. Alkalies not only act upon greasy matter, but, as is well known, dissolve all organic substances. In the case of soap, however, the solvent power of the alkali is in part neutralized, thus preserving both the texture and color of the fabric exposed to its action. The oily nature of the soap also increases the pliancy of the articles washed.

## § 3. *Lithium, Rubidium, Cæsium.*

**339. History.**—These three rare elements are found associated with potassium and sodium, to which they are closely allied in all their chemical relations. Lithium is a brilliant, silver-white metal, softer than lead, remarkably light, having a specific gravity of 0.578. We have already referred to its distribution (201).

Rubidium, also a soft, white metal, was discovered by means of the spectroscope. Its spectrum contains two dark-red lines; hence its name, from the Latin *rubidus*, meaning dark-red. Rubidium has been found in the ashes of many plants, in mineral water, in tobacco-leaves, in coffee, tea, cocoa, and crude tartar.

Cæsium was discovered at the same time with rubidium. The name comes from *cæsius*, sky-blue, and has reference to two blue lines in the spectrum.

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# CHAPTER XIV.

## SILVER.—GOLD.—BORON.

### § 1. *Silver and its Compounds.*

SILVER.—Symbol, Ag. (Argentum). Atomic Weight, 108; Quantivalence, I. and III.; Specific Gravity, 10.5.

**340. Metallic Silver** (*Molecule*) (Ag-Ag).—This well-known metal is frequently found native in fibrous crystalline masses. It is also found in combination with chlorine, sulphur, arsenic, or antimony. The principal silver-mines are those of Mexico and Peru. Silver is obtained from its ores by various processes, in some of which the ore is roasted with common salt, by which argentic chloride is formed; then, together with water, iron-scraps, and mercury, put into casks which revolve on their axes. The iron removes the chlorine, and the mercury amalgamates with the silver, from which it is afterward freed by *distillation* (III.).

From plumbic sulphide, which is by far the most important source of silver, it is obtained by first smelting for lead, and then volatilizing the lead by cupellation, a peculiar process, conducted in a furnace, the shallow, basin-shaped bottom of which is covered with a thick layer of bone, ashes, marl, or some other porous, infusible material. When the lead, alloyed with a small quantity of silver, is melted on this hearth, in a current of air, most of the lead oxidizes; the oxide or litharge melts, and, being absorbed by the cupel, leaves the silver pure.

**341. Properties and Uses.**—Silver is the whitest of the metals, with a bright, metallic lustre. It is very malleable, ductile, and tenacious. It may be extended into leaves not exceeding $\frac{1}{100000}$ of an inch, or $\frac{1}{4000}$ of a millimetre, in thickness; and one grain, or $\frac{1}{15}$ of a gramme, may be drawn out into 400 feet, or 122 metres of wire. Silver does not oxidize in the air at any temperature, but absorbs oxygen when melted, holding it mechanically, and giving it off on solidifying. It is a good conductor of heat and electricity, and its polished surface is one of the best reflectors of light. Silver is chiefly consumed in the manufacture of alloys used for coinage and silver-plate. Being too soft, pure silver is never employed for these purposes.

**342. Argentic Chloride** ($AgCl$.) (*Chloride of Silver*) is occasionally found native in mines, and is called *horn silver*, from its tough, horny texture. It may be prepared artificially by adding a solution of common salt to a solution of argentic nitrate, and appears as a white powder which darkens in color on exposure to light. Argentic bromide ($AgBr$) and argentic iodide ($AgI$) resemble the previous compound, and are found in a similar way.

**343. Argentic Monoxide** ($Ag_2O$) (*Silver Oxide*).—This substance is best prepared by mixing concentrated hot solutions of argentic nitrate and potassic hydrate. It is a black or bluish-black, heavy powder, slightly soluble in water. It is also formed when silver is heated in the air, but at a red heat, or even lower temperatures, it is completely decomposed, with formation of metallic silver and oxygen gas.

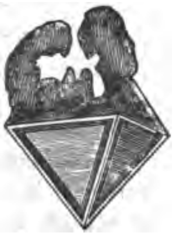
**344. Argentic Nitrate** ($AgNO_3$) (*Lunar Caustic*).—This interesting salt may be obtained by dissolving metallic silver in nitric acid; colorless, anhydrous crystals being formed, which are readily soluble in an equal weight of cold water. These crystals, when melted and cast into small sticks, form the lunar caustic of surgery. Argentic nitrate solution is decomposed by organic matter, with separation of black, finely-divided metallic silver, the reaction being most rapid when taking place in the light. Advantage is taken of this property in making indelible ink and hair-dye. A solution of potassic cyanide removes the stain thus produced.

## § 2. *Gold.*

Symbol, Au. (Aurum). Atomic Weight, 196.6; Quantivalence, I. and III.; Specific Gravity, 19.34.

**345. Gold** (molecular symbol of metal probably [$Au \equiv Au$]).—This is one of the most widely diffused of the metals, and generally occurs in minute grains, though sometimes in masses weighing many pounds. In 1851 a lump weighing 106 pounds was found in Australia, embedded in a matrix of quartz. It sometimes occurs in crystalline form, as shown in Fig. 140. As found in Nature, gold is rarely pure, but generally mixed with a variable quantity of silver. Gold is separated from all the constituents of its ores except silver, by amalgamation with mercury. It is obtained from silver by boiling the alloy in nitric acid, which dissolves out the silver, leaving the gold pure. In this operation, in order to prevent the silver from being mechanically protected from the action of the acid, it is necessary that there should be three times as much silver

FIG. 140.



Crystal of Gold.

as gold. As the gold constitutes only one quarter of the mass, the process is known as *quartation.*

**346. Properties.**—Gold is the only metal of a yellow color, it has a brilliant lustre, and high specific gravity. It is the most malleable of the metals, and to its ductility there is scarcely a limit; when pure it is nearly as soft as lead. It fuses at about 1200 C., and does not oxidize in the air at any temperature. Gold is not dissolved by any single acid, but is acted upon by chlorine, or any solution which liberates the gas. Its usual solvent is a mixture of four parts of hydric chloride and one of hydric nitrate, called, on account of its power to dissolve gold, *aqua regia.* The compounds of gold have little chemical interest to the ordinary student. $AuCl_3$ is somewhat used in the laboratory, and a solution of auric cyanide in potassic cyanide is used in electro-gilding.

## § 3. *Boron and its Compounds.*

BORON.—Symbol, B. Atomic Weight, II.; Quantivalence, III.; Molecular Weight, 22 (?); Molecular Volume, 2; Specific Gravity, 2.68.

**347. Boron.**—This substance is not found native, but may be prepared by decomposing fused boric oxide ($B_2O_3$) with sodium or aluminium. It exists in several modifications, being either brown, amorphous, and slightly soluble in water, or crystalline, and entirely insoluble. One of the two crystalline modifications known is exceedingly hard and brilliant, resembling the diamond in this respect.

**348. Boric Acid,** $H_3BO_3$.—This acid is found as a natural constituent of hot mineral springs, the principal locality being the "lagoons" of the volcanic district of Tuscany; where the acid issues from the earth with jets of steam, and is collected by throwing the jets into water. The acid is afterward separated from the water by evaporation in leaden pans so arranged that they are heated by the vapors as they escape from the earth. It is deposited in white, scaly crystals, which are purified by repeated crystallizations. These crystals have a glassy appearance, and are soapy to the touch. They dissolve much more readily in boiling than in cold water, and form a solution having feebly acid properties.

**349. Hydro-Sodic Borate** ($Na_2H_2B_4O_8 + 9H_2O$) (*Borax*).—This salt is found native at the bottom of certain lakes in Thibet and California. It is procured artificially by heating boric acid with sodic carbonate, decomposition taking place with evolution of carbonic dioxide. Borax has an alkaline taste and reaction, and in the fused state, at a high heat, possesses the property of dissolving many metallic oxides; hence its use as a flux in the welding of metals. It dissolves the coating of oxide formed when the metals are heated, which thus constantly present a clean surface. On account of the same property it is one of the most important reagents, being chiefly employed in blowpipe analysis.

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# CHAPTER XV.

## THE NITROGEN GROUP.—NITROGEN, PHOSPHORUS, ARSENIC, ANTIMONY, BISMUTH.

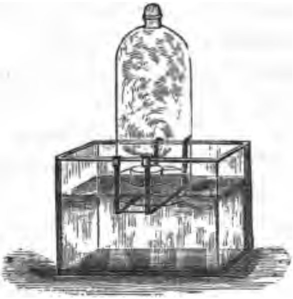
### § 1. *Nitrogen and its Compounds.*

NITROGEN.—Symbol, N. Atomic Weight, 14; Quantivalence, I., III., and V.; Molecular Weight, 28; Molecular Volume, 2; Specific Gravity, 0.972.

**350. Nitrogen Gas** (*Molecule*) ($N \equiv N$).—This gas was discovered by Rutherford, in 1772. Chaptal afterward gave it the name nitrogen, signifying generator of nitre. It is very extensively diffused in Nature, forming about four-fifths of the atmosphere, in which it plays the important part of diluting the oxygen, and adapting it to the conditions of life. It is the characteristic ingredient of animal tissue, and is never entirely absent from plants, while of many important vegetable products it is an essential constituent, as for example, of the vegetable alkaloids.

**351. Preparation.**—Nitrogen is most commonly prepared by withdrawing the oxygen from a portion of air. A small bit of phosphorus is placed in a little cup and floated on the water in a pneumatic trough. It is then set on fire and a jar placed over it, as in Fig. 141. The phosphorus takes the oxygen, forming phosphoric pentoxide, which fills the jar with a white vapor; but this is soon absorbed by the water, and nitrogen alone is left, the water rising to occupy the space of the vanished oxygen.

FIG. 141.



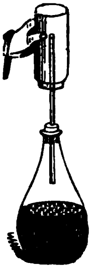
Preparation of Nitrogen.

**352. Properties.**—Nitrogen is a transparent gas, without taste or color, and has never been condensed into a liquid. It is remarkable for chemical inertness. It is irrespirable; animals placed in it quickly die, not from its poisonous action, but from lack of oxygen. It supports the combustion of but few substances; a lighted taper introduced into it is immediately extinguished. Boron, titanium, and a few other rare bodies, burn in it, with the formation of nitrides. It is slightly soluble in water, one hundred volumes of the latter, at 15° C., taking up about one and a half volume of the gas. Although nitrogen combines *directly* with only two elementary substances, boron and titanium, it has great capacity for combination, and is distinguished by the large number and variety of its compounds.

**353. Hydric Nitride or Ammonia** ($H_3N$).—This substance was first described by Priestley, in 1774. It is frequently met with in Nature, being a constant product of the decomposition of organic substances which contain nitrogen. It is produced from the destructive distillation of horns and hoofs, which are rich in nitrogen, but the chief source of commercial ammonia is the liquor of the gas-works. Ammonia gas is conveniently obtained by the action of one part of quick-lime, CaO, upon two parts of ammonic chloride, $NH_3HCl$, in a glass flask or retort. The reaction is thus shown:

$$(NH_3HCl)_2 + CaO = CaCl_2 + H_2O + (H_3N)_2.$$

FIG. 142.



Producing Ammonia.

It will be seen that the lime takes the hydric chloride, forming calcic chloride, while water and ammonia are set free. The gas may be collected in jars in the pneumatic trough, but it must be over *mercury*, as water absorbs it. It is, however, more convenient to procure it by what is called the method of *displacement*. The gas generated in the lower vessel (Fig. 142) being lighter than the air, accumulates in the upper portion of the inverted jar, displacing the air and expelling it downward.

**354. Properties.**—Ammonia is a colorless, irrespirable gas of a pungent, caustic taste, lighter than air (sp. gr. 0.59), and possesses strong alkaline properties, changing vegetable blues to green and yellows to brown, whence it is called volatile alkali. It does not support combustion or respiration; a thin stream of the gas may be ignited in the air, and burns with a pale flame. It may be condensed by cold or pressure, both to the liquid and the solid state. Liquid ammonia is a colorless, mobile fluid. In the solid state it is white, transparent, and crystalline. From the circumstance that it was derived from the horns of harts, it was called *spirits of hartshorn.* Ammonia is recognized by its odor.

FIG. 143.

Testing Ammonia.

If a rod dipped in hydric chloride be brought near a source of ammonia, a white cloud is produced by the formation of ammonic chloride ($NH_4Cl$). (Fig. 143).

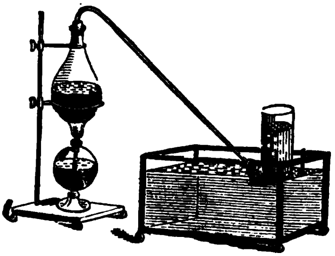
**355. Uses.**—Ammonia is used medicinally in various ways. It is administered internally as a stimulant, and applied externally as a counter-irritant. Mixed with olive-oil, it forms *volatile liniment.* It is the best antidote to prussic acid, but in large doses it is poisonous. It is of many uses to the chemist.

**356. Oxides and Acids of Nitrogen.**—Nitrogen combines with oxygen, forming:

| | |
|---|---|
| Nitric monoxide, $N^{I}_2O$. | |
| Nitric dioxide, $N^{III}_2O_2$. | |
| Nitric trioxide, $N^{III}_2O_3$. | Nitrous acid, $HN^{III}O_2$. |
| Nitric tetroxide, $N^{V}_2O_4$. | |
| Nitric pentoxide, $N^{V}_2O_5$. | Nitric acid, $HN^{V}O_3$. |

**357. Nitric Monoxide** ($N_2O$) (*Nitrous Oxide*).—This compound was discovered, in 1776, by Priestley, and further examined by Davy in 1800, who noticed the exhilarating effects produced by the respiration of this gas, from which its popular name, "*laughing gas,*" is derived. It is prepared from ammonic nitrate, by moderately heating this salt in a flask. The gas escapes through a tube, and is collected in jars over water (Fig. 144). It should be allowed to stand for some time over water, to absorb any nitrous acid that may chance to be formed. The chemical change may be represented by the equation,

FIG. 144.



Preparation of Nitrous Oxide.

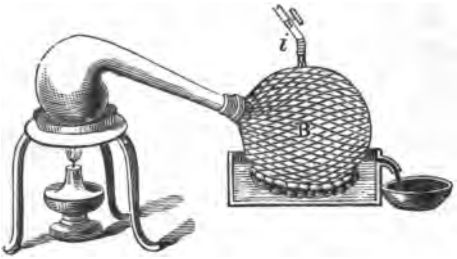
$$N_2H_4O_3 = 2H_2O + N_2O,$$

one molecule of ammonic nitrate yielding two molecules of water and one of nitric monoxide.

**358. Properties.**—At ordinary temperatures nitric monoxide is a neutral, colorless, transparent gas, of a slightly sweetish taste, and very soluble in water—cold water absorbing about three-fourths of its volume. Sp. gr. 1.527. It is an active supporter of combustion, relighting a glowing candle when plunged into it, and intensifying the combustion of phosphorus almost equally with pure oxygen. A pressure of 50 atmospheres at 45° F. condenses it into a clear liquid which boils at about 1126° F., and may be frozen at about −150° F. When breathed in small quantities this gas produces a transient intoxication, attended sometimes by an irresistible propensity to laugh, and at others by a tendency to muscular exertion, individuals being variously affected according to temperament. The gas should be pure, and even then the experiment is not a safe one for some constitutions. Inhaled in larger quantities it produces insensibility, hence it is now much employed by dentists as an anæsthetic.

**359. Hydric Nitrate or Nitric Acid** ($HNO_3$).—This compound, familiarly known as *aqua-fortis*, is not found in Nature, but has been known since very early times. It is produced on a large scale by the decomposition of sodic nitrate with sulphuric acid: 100 parts, by weight, of sodic

FIG. 145.



Liberation of Nitric Acid.

nitrate, 117 parts concentrated sulphuric acid, and 30 parts of water, are placed in a glass retort which is supplied with a receiver *B*, kept cool by cold water flowing over it from the tube *i*, by means of a netting (Fig. 145). With the application of heat, the nitrate is decomposed, and the acid distils over into the receiver. The change is thus shown:

$$NaNO_3 + H_2SO_4 = NaHSO_4 + HNO_3.$$

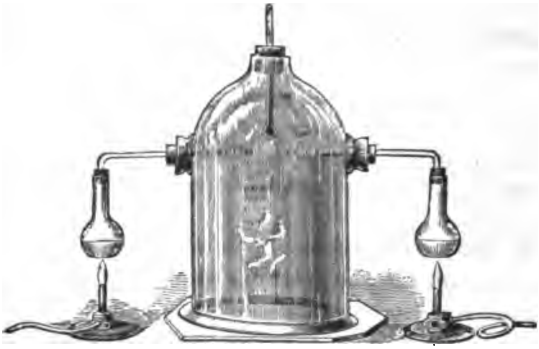
That is, one molecule of sodic nitrate and one of sulphuric acid furnish one molecule of nitric acid and one of hydrosodic sulphate.

**360. Properties.**—Nitric acid is a colorless, mobile liquid, of 1.52 specific gravity, fuming in contact with the air, and possessed of an intensely sour taste and peculiar sweetish-nauseous pungent smell. It becomes solid at very low temperatures, and boils at 86° C., with partial decomposition. It is highly corrosive, and stains of a yellow color the skin, nails, and many other animal substances; it is therefore used to produce yellow patterns upon woolen fabrics. It is also employed for etching on copper, for assaying or testing metals, and, by dyers and calico-printers, as a solvent for tin. In consequence of its large proportion of oxygen, it corrodes the metals with great energy, and hence is the most powerful of oxidizing agents. It ignites powdered charcoal and oil of turpentine, and oxidizes phosphorus so rapidly as to produce an explosion.

**361.** A mixture of chlorohydric acid with nitric acid constitutes the *aqua regia*, or royal water, of the alchemists, so named from the power it possesses of dissolving gold, the "king of metals," a property due to the presence of chlorine, which, at the moment of its formation, attacks metals with great energy. The proportions for the mixtures are four measures of hydric chloride to one of nitric acid.

**362. Ammonic Chloride** ($NH_4Cl$) (*Sal-ammoniac*).—This substance is found native in many volcanic regions, in the vicinity of burning coal-mines, and in guano-deposits.

Fig. 146.



Formation of Ammonic Chloride.

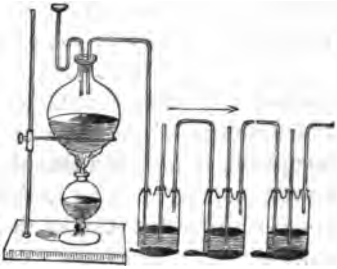
When hydric chloride and ammonia are brought together, they form dense white clouds of sal-ammoniac, as may be seen in Fig. 146. The reaction is expressed thus:

$$\underset{\text{Ammonia Gas.}}{NH_3} + \underset{\text{Hydric Chloride.}}{HCl} = \underset{\text{Ammonic Chloride.}}{NH_4Cl.}$$

When a solution of ammonic hydrate is neutralized by hydric chloride, crystals of ammonic chloride are produced, which have a sharp taste, and dissolve in thrice their weight of cold water. Sal-ammoniac is chiefly obtained by neutralizing the ammoniacal liquor of the gas-works by hydric chloride. On evaporating the resulting solution, the salt appears in the form of the tough, fibrous crystals of commerce. It is volatilized by heat. Mixed with lime, which decomposes it and expels the ammonia, it is used in smelling-bottles.

**363. Ammonic Hydrate** ($NH_5O$) (*Aqua Ammonia*).—This compound is prepared by passing ammonia gas ($NH_3$) into water, which absorbs it rapidly to the extent of 700 times its own volume. The gas is evolved by gently heating a mixture of slacked lime and sal-ammoniac, and passing it through a series of bottles. In making solutions of the absorbable gases several difficulties have to be guarded against. The action in the evolution-flask is liable to various interruptions, while the water present in the apparatus rapidly absorbs the gas. This creates a partial vacuum, and the consequence is, that the water in the jar flows back into the flask, thus putting an end to the process; also, if the gas is generated faster than it is absorbed, there arises the danger of an explosion, unless there is a free outlet to the apparatus. These dangers are obviated by the arrangement known as Woulfe's bottles (Fig. 147).

FIG. 147.



Woulfe's Bottles.

The flask in which the gas is generated is provided with a safety tube which serves both as a means of introducing a liquid and as a protection against the above-mentioned accidents. When the liquid is poured in, a portion of it is retained in the bend of the tube, acting there as a valve to prevent the access of air to the flask. Each bottle has an upright tube in the middle neck which acts as a safety-tube, allowing the air in case of a vacuum to pass in, or the liquid in flow out, if the pressure of the gas becomes too great. The other tubes serve to connect the bottles with the flask and with each other.

**364. Properties.**—Ammonic hydrate is a colorless, transparent liquid, of 0·85 specific gravity, with the pungent odor of ammonia, and a sharp, burning taste. As usually met with, it is rarely a definite compound, being liable to contain either more water or gas than the above formula implies. A saturated solution freezes between —38° and

—41° C., forming shining, flexible, needle-shaped crystals. It boils at 130° F., but is, at the same time, decomposed with evolution of ammonia. The graphic formula of ammonic hydrate is $(H_4)\equiv N\text{-}O\text{-}H$. The single atom of hydrogen which is linked to the one oxygen-atom is replaceable by negative radicles; the resulting compounds are termed ammoniacal salts. These salts are remarkable as being isomorphous with certain potassic compounds, and when the formulas of any two of these isomorphous salts are compared, it is found that the atomic group $H_4N$ exactly corresponds in function to the radical potassium. Thus in comparing the formulas of the two well-known isomorphous salts—

Potash-alum $K \quad AlS_2O_8 + 12H_2O$, and
Ammonia-alum $H_4N \quad AlS_2O_8 + 12H_2O$,

we readily observe this analogy. On account of this remarkable fact, it has been assumed that the atomic group, $H_4N$, or its double molecule $(H_8N_2)$, must be very similar in character to potassium, and possessed of metallic properties. This radical has been named *ammonium.*

**365. Ammonic Nitrate,** $(H_4N)\ NO_3$, is formed in small quantities during thunder-storms, and is sometimes contained in rain-water. Ammonic sulphate, $(H_4N)_2\ SO_4$, is a valuable fertilizer. Several ammonic carbonates are known, and the commercial ammonic carbonate, when purified, constitutes the volatile salts, or smelling-salts, of the shops.

## § 2. *Phosphorus and its Compounds.*

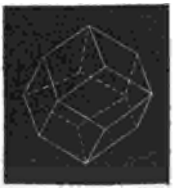
PHOSPHORUS.—Symbol, P. **Atomic Weight, 31; Molecular Weight, 124; Molecular Volume, 2; Quantivalence, I., III., V.; Specific Gravity,** 1.82.

**366. Distribution.**—Phosphorus is found in Nature chiefly in combination with calcium. It is a never-failing constituent of the plants used by man and the domestic animals. It is an equally important ingredient of animal skeletons, which owe their strength to calcic and magnesic phosphates, while it also exists in other combinations in the blood, flesh, milk, and other tissues, and secretions of animals. Phosphorus exists in several allotropic states. Ordinarily, it is a white solid, with a faint-yellow tinge, and almost transparent; when exposed to light under water, it gradually becomes white, opaque, and scaly. Exposed to direct sunlight under water, phosphorus becomes covered with a red coating, and the same modification is formed when ordinary phosphorus is heated to a temperature below 250° C., in a gas which has no action upon it. None of the modifications are found native.

**367. Ordinary Phosphorus** ($P_4$).—This interesting body was discovered in 1669 by Brandt, who obtained it by distilling the residue of evaporated urine with charcoal. Most of the phosphorus of commerce is obtained by the decomposition of the bones of animals, which consist largely of calcic phosphate ($Ca_3P_2O_8$). The bones are first burned, and, the organic matter being consumed, they are reduced to powder and soaked in concentrated sulphuric acid. This decomposes the phosphate, with formation of insoluble calcic sulphate, and soluble acid calcic phosphate ($CaH_4P_2O_8$). The solution of this compound, after being separated from the sulphate, evaporated to sirupy consistence, mixed with charcoal, and heated in an iron pot, is distilled at a bright-red heat. The carbon unites with the oxygen, liberating the phosphorus, which rises in vapor, and is condensed in water in the shape of yellow drops. These are melted under water and forced into tubes, thus forming the ordinary stick-phosphorus.

**368. Properties.**—Phosphorus is a soft, colorless, half-transparent, waxy solid, so extremely inflammable that it takes fire in the open air by the heat of the slightest friction, and burns with great violence, emitting a brilliant flame, and dense, white fumes of phosphoric pentoxide. If quietly exposed to the air, it undergoes slow oxidation, emitting white vapors of a garlic odor and shines in the dark, whence its name, phosphorus, *bearer of light*. It must be handled with caution, as the burns it produces are deep and difficult to heal. It is insoluble in water; partially soluble in ether, but dissolves readily in carbonic disulphide and various oils. It melts at 44° C., forming a viscid, oily liquid. In warm weather phosphorus is flexible, and may be bent without breaking, but near the freezing-point of water it becomes brittle, exhibiting a cystalline fracture. On account of its inflammability it is kept under water. It crystallizes from its solution, in forms of the monometric system (Fig. 148). Solutions of phosphorus, as well as the solid itself, are luminous in the dark. Phosphorus is a violent poison. The chief use of this substance is in the manufacture of friction-matches; and vast quantities are consumed in this way among all civilized nations.

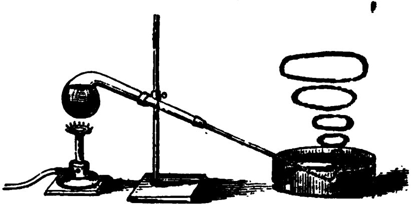
FIG. 148.



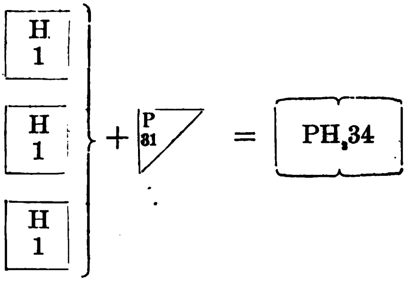
**369. Red Phosphorus.**—This substance may be obtained by exposing ordinary phosphorus to sunlight, or heating it to near its boiling-point in an atmosphere free from oxygen. As thus prepared, red phosphorus, also known as amorphous phosphorus, is a red powder, of about 2.18 specific gravity, much less fusible than ordinary phosphorus, but reverting into the latter at about 260° C. It exhales no vapor or odor; oxidizes but very slowly in the air, does not change oxygen into ozone, is chemically indifferent, may be handled with impunity, or carried exposed in the pocket, and is not poisonous. Phosphorus forms three compounds with hydrogen, but only one is of importance to the ordinary student.

**370. Hydric Phosphide** ($H_3P$) (*Phosphuretted Hydrogen*).—This is a colorless gas, with a very offensive odor, like rotten fish. It is found in Nature, being produced in small quantities by the decay of animal matter, and appears to be the cause of the will o' the wisp. It may be prepared by heating small fragments of phosphorus with a strong solution of caustic potash in a retort. The end of the retort-tube dips beneath water, and, as the gas passes out in bubbles, it rises to the surface and takes fire spontaneously. If some pieces of calcic phosphide are thrown into a glass of water, the same thing takes place. Double decomposition with the water produces hydric phosphide, which ignites at the surface and forms beautiful wreaths of vapor (Fig. 149). Pure hydric phosphide ($H_3P$) is, however, not spontaneously inflammable, this property being due, in this case, to the admixture of a minute quantity of a liquid compound ($H_4P_2$). It is poisonous. In many cases the combining weights and the unit-volume weights are identical. But the atomic weight of phosphorus is 31; while the specific gravity of its vapor has been found to be 62.1. The volumetric composition of hydric phosphide will be readily understood by reference to the accompanying diagram:

Fig. 149.

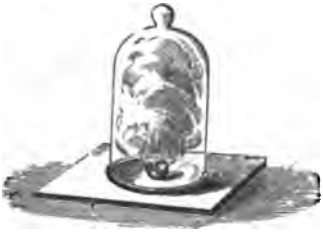


Wreaths of Flame.



**371. Phosphoric Pentoxide** ($P_2O_5$).—When phosphorus is burned in dry oxygen (Fig. 150), the dense, white vapors which are formed condense upon the glass in snow-like flakes. This is phosphoric pentoxide. It has a powerful attraction for moisture, absorbing it from the air, or, if brought into contact with water, seizing it with such violence as to emit a hissing sound. By the union of phosphoric pentoxide with water, there are formed three distinct acids: meta-phosphoric acid ($HPO_3$), pyro-phosphoric acid ($H_4P_2O_7$), and ortho-phosphoric acid ($H_3PO_4$).

FIG. 150.



Combustion of Phosphorus.

## § 3. *Arsenic and its Compounds.*

ARSENIC.—Symbol, As. Atomic Weight, 75; Quantivalence, III. and V. Molecular Weight, 300; Molecular Volume, 2; Specific Gravity, 5.79.

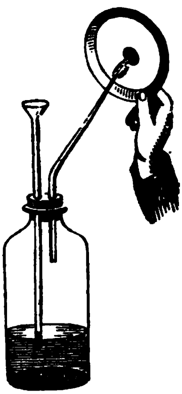
**372. Arsenic.**—This element is found native, but most of the arsenic of commerce is obtained by the decomposition of the arsenides. The compounds are heated in retorts of earthen-ware; the arsenic sublimes and collects in iron tubes and earthen receivers.

Arsenic is a brittle metal, of a steel-gray, or nearly white color. The coarse, gray powder, sold under the name of "fly-poison," or "cobalt," is an impure arsenic. When arsenic is heated in a close vessel to 356° F., it volatilizes without fusion, giving off a dense, colorless vapor, having the peculiar odor of garlic, and corresponding to the formula $As_4$. If heated in the open air it takes fire, burning with a blue flame, with formation of arsenic trioxide. It is highly poisonous.

**373. Hydric Arsenide** ($H_3As.$) (*Arseniuretted Hy-*

*drogen*).—This gas may be formed by decomposing an alloy of arsenic and iron with dilute sulphuric acid, or by introducing a solution of arsenic into a flask in which hydrogen is being evolved. It burns with a bluish-white flame, is highly poisonous, and of a disgusting odor. The formation of this gas is used for the detection of arsenic by Marsh's test. Fig. 151 shows the form of an apparatus which answers, in a rough way, very well for this purpose. Bits of zinc and a little water are placed in the vessel, which is provided with a cork through which a tube is inserted. Sulphuric acid is now poured in through the funnel-tube, and the evolution of hydrogen commences. After the air has been completely expelled from the flask, the gas may be lighted at the jet. If the solution containing arsenic be now poured in through the funnel-tube, the color of the flame immediately changes, and a cold, white surface, held so as to cut the flame in half, is stained with a black or brown spot by the deposition of metallic arsenic. Antimony produces a similar effect, but a solution of calcic or sodic hypochlorite dissolves the arsenical stain, leaving that made by antimony unchanged. This is a very delicate test, but great care should be taken that the sulphuric acid and zinc do not contain any previous traces of arsenic. It is estimated that $\frac{1}{50000}$ of a grain of arsenious oxide in one hundred grain measures of the solution may be detected by this test.

FIG. 151.



Marsh's Test.

**374. Arsenic Trioxide** ($As_2O_3$) (*Arsenious Acid*).—This compound occurs native, but is also prepared on a large scale by roasting certain ferric arsenides, and other arsenical ores. Thus obtained, it constitutes the well-known white arsenic or ratsbane of commerce, a white solid body, capable of existing in three isomeric forms. It is soluble in about ten parts of hot water, the solution having a slightly sweetish taste, and acid reaction. It also dissolves readily in hot hydric chloride, and in solutions of the alkaline arsenites. It is used in dyeing and calico-printing, in glass-making, and for the preparation of arsenical soap, which is employed for preserving stuffed animals. Though a violent, corrosive poison, it is used in medicine; its most effectual antidotes are the moist hydrated ferric oxide and caustic magnesia. *Ortho-arsenic acid* ($H_3AsO_4$) is formed by oxidizing arsenious oxide by means of nitric acid. It has strongly acid properties, decomposing the carbonates with effervescence. *Arsenic disulphide* ($As_2S_2$) has been known since very remote times, and is found native as realgar, a mineral crystallizing in translucent, oblique, rhombic prisms, of beautiful orange-yellow, or ruby-red, color. It is produced artificially, is used as a pigment, and in the preparation of the pyrotechnical mixture known as "Bengal white-light." *Arsenic trisulphide* ($As_2S_3$), familiarly known as "orpiment," is found native, but is also prepared artificially. It is a bright-yellow substance, and is used in dyeing to reduce indigo, and also in the preparation of "rusma," a paste employed to remove the hair from skins.

## § 4. *Antimony and Bismuth.*

ANTIMONY.—Symbol, Sb. (Stibium). Atomic Weight, 122; Quantivalence, III. and V.; Molecular Weight, 488 (?); Molecular Volume, 2; Specific Gravity, 6.78.

**375. Antimony** is found native, though most of the antimony of commerce is obtained from the trisulphide ($Sb_2S_3$). It exists in two modifications; ordinarily it is a brittle, brilliant, bluish-white metal, crystallizing in rhombohedrons. The other form is obtained by electrolysis, and has a specific gravity of 5.78. When struck or heated it suddenly reverts to the previous modification, with great evolution of heat. Antimony melts at 450° C., and vaporizes at a white heat. Heated in the air it burns with a white flame. The alloys of antimony are of great use in the arts. Of these, type-metal, an alloy of lead and antimony, is the most important. The detection and separation of arsenic and antimony is a subject of much importance as both alike exhibit poisonous characters and similar reactions (373). *Stibic trioxide* ($Sb_2O_3$) is produced when metallic antimony burns in the air. It is white, crystalline, isomorphous with arsenic trioxide, sparingly soluble in water. It is used as a pigment in place of white lead, and gives rise to the salts of antimony so much used in medicine. *Stibic trisulphide* ($Sb_2S_3$) is employed in veterinary surgery, in pyrotechny, and in the preparation of the percussion pellets used in the cartridges of the Prussian needle-gun.

BISMUTH.—Symbol, Bi. Atomic Weight, 210; Quantivalence, III. and V.; Specific Gravity, 9.8.

**376. Bismuth.**—This metal, which has long been known, is found, in the metallic state, in veins in gneiss, clay, slate, and other crystalline rocks, chiefly in Saxony and Bohemia. The commercial material is derived from the native metal by purification. It is hard, brittle, reddish-white in color, and crystallizes from fusion in rhombohedrons. It melts at 264° C., and on solidifying expands one thirty-second of its bulk. It is volatile at high temperatures. Heated in the air it burns with a bluish flame, giving rise to yellow fumes. Bismuth is used in the arts alloyed with other metals, and its compounds are used in medicine and as pigments.

# DIVISION II.—ARTIAD ELEMENTS.

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## CHAPTER XVI.

### § 1. *Oxygen and its Compounds.*

OXYGEN.—Symbol, O. Atomic Weight, 16; Quantivalence, II.; Molecular Weight, 32; Molecular Volume, 2; Specific Gravity, 1.1056.

**377. Modifications of Oxygen.**—Oxygen is known to us in three modifications, consisting, apparently, of one, two, and three atoms of the radical bearing the same name. The second, only, of these is generally termed *oxygen;* the molecule containing three atoms of the radical oxygen is known as *ozone*, and the body containing only one atom as *antozone.*

**378. Oxygen** (*Ordinary Modification*) ($O_2$).—This gas was discovered in 1774, by Dr. Priestley, and the following year it was discovered, independently, by Scheele. Its discovery was also claimed by Lavoisier, who, in 1781, gave it the name oxygen, from two Greek words, meaning acid-former. This has been justly pronounced the capital discovery of the last century, rivaling in importance the great discovery of gravitation, by Newton, in the preceding century. It formed one of the great eras in the progress of human knowledge; it put an end to old theories, laid the foundation of modern chemical science, and furnished the master-key by which man has been enabled to open the mysteries of Nature. But while the discovery of gravitation is unsurpassed in grandeur, that of oxygen is far more vitally linked with the course of earthly affairs.

**379.** Of its vast practical consequences, Professor Liebig observes: "Since the discovery of oxygen, the civilized world has undergone a revolution in manners and customs. The knowledge of the composition of the atmosphere, of the solid crust of the earth, of water, and of their influence upon the life of plants and animals, was linked with that discovery. The successful pursuit of innumerable trades and manufactures, the profitable separation of metals from their ores, also stand in the closest connection therewith. It may well be said that the material prosperity of empires has increased manifold since the time oxygen became known, and the fortune of every individual has been augmented in proportion."

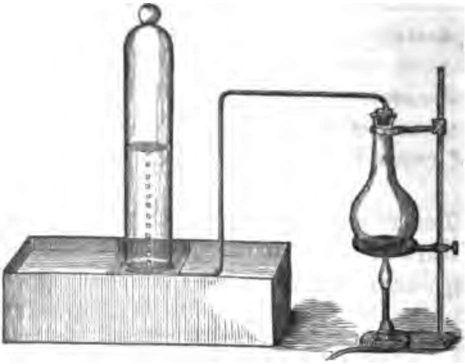
**380. Occurrence.**—Oxygen is the most abundant element in Nature. It is of universal distribution through our atmosphere, forming one-fifth part of the air we breathe. The total quantity contained in the atmosphere has been computed to be about 1,178,158,000,000,000 tons, which, if forming a separate layer of uniform density upon the earth's surface, would be one mile deep. It constitutes eight-ninths of water by weight, besides being a constituent of nearly all the rocks of the globe; and entering largely into the organized structure of plants and animals.

**381. Preparation.**—Oxygen may be procured in many ways. Mercuric oxide and manganic dioxide readily yield it when they are exposed to a high temperature. It can be obtained in larger quantity, and very pure, from potassic chlorate. Two hundred grains of the salt, or about fourteen grammes, are placed in a glass flask, which is fitted tightly with a cork, containing a glass tube, bent so as to dip under the shelf of the pneumatic trough (Fig. 152). The flask is heated, and the chlorate gives off more than a third of its weight of gas. This salt consists of potassium, chlorine, and oxygen, and in the change the whole of the oxygen is disengaged, potassic chloride remaining behind.

$$2KClO_3 = 2KCl + 3O_2.$$

The decomposition of the chlorate is much facilitated by mixing with it one-fourth its weight of cupric oxide, or manganic dioxide, thoroughly dried. These substances take no active part in the change, but seem to aid the decomposition by simple presence (catalysis).

FIG. 152.

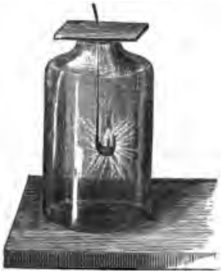


Generating Oxygen Gas.

**382. Properties.**—Oxygen is a transparent, colorless, tasteless, inodorous gas. It is about $\frac{1}{10}$ heavier than atmospheric air. It has never been condensed into a liquid. The refractive power of oxygen compared with that of air as unity is 0.8616. It possesses magnetic properties, but loses them at a high temperature. Oxygen is slightly soluble in water, 100 volumes of which absorb about $4\frac{1}{2}$ of the gas.

Oxygen is perfectly neutral, possessing neither acid nor alkaline qualities, but, though apparently the very type of passiveness, this substance is endowed with the most intense power. The two atoms of the radicle, which together form a molecule of oxygen gas, are held by but feeble attraction, and are easily severed, when they enter into new and firmer combinations.

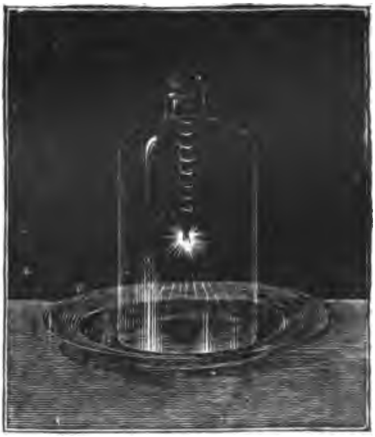
Fig. 153.



Taper in Oxygen.

**383. Combustion in Oxygen.**—The oxygen of the air (about one-fifth of its weight) is equally diffused throughout it. All combustion in the open air is the result of the action of oxygen. It has a powerful affinity for the elements of which fuel is composed, and unites with them with such violence as to give rise to the heat and light of our ordinary fires. All substances which burn in air, burn in pure oxygen with greatly increased brilliancy. If the flame of a taper (Fig. 153) be extinguished, and a single spark remain upon the wick, on plunging it into a jar of pure oxygen, it will be relighted and burn with extreme vividness; and this may be repeated many times in the same vessel of gas. The combustion of a splinter of wood is brilliant, and a piece of bark charcoal glows and scintillates in the most beautiful manner.

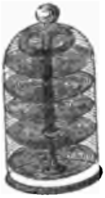
Fig. 154.



Combustion of Iron in Oxygen.

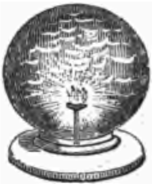
**384.** Substances usually considered incombustible also burn violently in oxygen. If a piece of fine iron wire (or, better still, a steel watch-spring) be coiled into a spiral and then tipped with sulphur, ignited and introduced into a jar of oxygen, it burns with dazzling brilliancy and splendid corruscations (Fig. 154). Occasionally globules of white-hot iron fuse into the glass even through an inch depth of water. If a jar of oxygen be inverted over a stand upon which there is a little burning sulphur, a beautiful blue light is emitted, and the fumes produced circulate round in curious rings (Fig. 155). If phosphorus be burned in the same manner, a blinding flood of light is produced, accompanied by great heat (Fig. 156). In all these cases, the effects are due simply to the union of oxygen with the burning body, and, could we have weighed them before the experiment, and the products of combustion afterward, they would have been found precisely equal.

FIG. 155.



Burning of Sulphur.

FIG. 156.



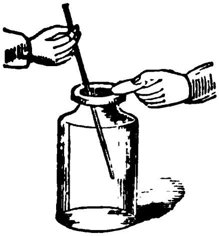
Phosphorus burning in Oxygen.

**385. Eremacausis.**—The cause of decay in vegetable and animal substances is the action of oxygen, which breaks them up into simpler and more permanent compounds. This slow combustion is called by Liebig *eremacausis.* Oxidation is also the grand process by which the earth, air, and sea, are purified from contaminations; noxious vapors and pestilential effluvia being destroyed by a process of burning, more slow indeed, but as real as if it took place in a furnace. The offensive impurities which constantly flow into rivers, lakes, and oceans, as well as the decaying remains of the living tribes which inhabit them, are perpetually oxidized by the dissolved gas, and the water thus kept pure and sweet. In this way waters that have become foul and putrid are purified and sweetened by exposure to the action of air. This effect, however, is largely dependent upon the presence of ozone.

**386. Relation of Oxygen to Life.**—Oxygen is the universal supporter of respiration, and hence, as this is the most important of the vital processes, it is the immediate supporter of life. From this circumstance it was first known as *vital air.* An animal confined in a given bulk of common air, having consumed its oxygen, dies. If immersed in pure oxygen, it lives much longer, but the effect is too powerful—over-action, fever, and in a short time death, are the result. As the introduction of oxygen is the prime physiological necessity of animal life, the mechanism of all living beings is constructed with reference to this fact. The lungs of the higher races, the spiracula of insects, and the gills of fishes, are all adapted to the same purpose—the absorption of oxygen, either from the air or water. The animal organism is chiefly composed of combustible constituents, and we introduce this wonderful element incessantly, day and night, from birth to death, that it may perform its chemical work. The animal body is an oxidizing apparatus, in which the same changes occur that take place in the flame, only in a lower degree, and a more regulated way. Every organ, muscle, nerve, and membrane, is wasted away, burnt to poisonous gases and ashes, and thrown from the system as dead and dangerous matter. If these constant losses are not repaired by the due supply of food, emaciation, decay, and finally death ensue. Starvation is thus unimpeded oxidation—slow burning to death.

**387. Ozone** ($O_3$).—When electric sparks are passed through dry air, a peculiar odor is perceived, which has been called the "electrical smell." There was much doubt about the cause of it, until the investigations of Schönbein, and of Marignac, and De la Rive, showed that it was due to an allotropic form of oxygen. From its peculiar odor, its discoverer named it *ozone.* In Nature this modification of oxygen is found principally during and after thunderstorms; but the quantity contained in the atmosphere varies considerably, and is always small. Winds blowing from the sea are said to contain more of it than those which sweep over large tracts of land. Oxygen may be converted into ozone not only by electricity, but in various other ways. Thus, when a spiral of platinum wire is heated in air, or when light acts upon some essential oils, in contact with air, ozone is formed. If a piece of phosphorus be placed in a jar, and partially covered with water, its slow oxidation will soon produce ozone. Or, if we place a little ether in an open vessel, and then introduce into its vapor a moderately heated glass rod (Fig. 157), ozone promptly appears.

FIG. 157.

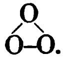


Preparation of Ozone.

**388. Properties.**—In most of its physical properties ozone resembles the ordinary modification of oxygen. It differs from it in possessing a powerful odor, somewhat resembling dilute chlorine gas. Its molecular weight is 48, and its density 24. It is soluble only in oil of turpentine. The most remarkable property of ozone is its powerful oxidizing action. In fact, it is oxygen greatly intensified in activity. It corrodes metals upon which ordinary oxygen could not act, for example, silver; it quickly bleaches colors, which are comparatively permanent in the air; it deodorizes tainted flesh, destroying its effluvium instantly, and carries woody fibre in a short time through a course of decomposition, which, with common oxygen, would require years. It decomposes potassic iodide, setting the iodine free. Free iodine combines with starch, turning it blue; therefore, a test of ozone is made by soaking slips of paper in a mixture of starch and potassic iodide. The slightest trace of ozone turns it immediately blue. Prepared paper, exposed for a few minutes to the open air, will frequently turn blue, which is supposed to be due to the presence of ozone. It is probable that it is generated on a large scale in the atmosphere, and that it subserves a high purpose in the economy of the globe as a purifier of the air, and hastener of decay. Ozonized air irritates the respiratory organs, and a minute quantity kills a rabbit. At a temperature of 290° C., ozone is reconverted into ordinary oxygen.

**389. Antozone** ($O_1$).—The existence of this substance is yet somewhat doubtful. It is supposed to be produced, together with ozone, by the action of the silent electric discharge upon oxygen. On passing the electrized gas through a solution of potassic iodide, the ozone is absorbed, and the antozone mixed with the excess of unaltered oxygen remains. When this is passed through water it forms a peculiar dense mist, which, collected by itself, disappears after a little time, depositing only pure water. Antozone is reconverted into ordinary oxygen, under the same conditions as ozone, but the reconversion takes place more readily in the presence of the latter. Antozone has an odor similar to ozone, but is much more repulsive.

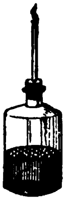
The molecule of ordinary oxygen is regarded as constituted according to the graphic formula O=O. As the density of ozone is to that of ordinary oxygen as 3 : 2, the ozone-molecule is assumed to be made up of three atoms of the radicle oxygen. When two molecules of ordinary oxygen are ozonized, three of the four constituent atoms combine to form ozone. It is, therefore, held that antozone consists of the one remaining atom. The molecular and graphic formulas of the three forms of oxygen exhibit the following relations:

| | Antozone. | Oxygen. | Ozone. |
|---|---|---|---|
| Molecular, | $O_1$ | $O_2$ | $O_3$. |
| Graphic, | O> | O=O |  |

**390. Hydric Oxide** ($H_2O$), **Water.**—Of the importance of water in the economy of Nature little need be said; it is obvious to all. It is the most abundant substance that we know, and it seems as if the whole scheme of Nature were conformed to its properties. Turning to solid ice, or exhaling into invisible vapor, its changes of form involve the very history of the globe. Rising from the ocean, condensed upon the land, and flowing back again to the sea, it carries on in its circulation the grand processes of the world. Constituting four-fifths the weight of the vegetable kingdom, and three-fourths that of the animal, it is the first condition of all organization, and by innumerable transformations and decompositions it is essential to the continuance of organic life. Nor is it less indispensable in the laboratory of the chemist. It is the ready, invaluable medium of a thousand operations, and is involved in nearly every chemical process.

**391. Production of Water.**—If hydrogen is generated in a jar and allowed to escape through a fine tube (Fig. 158) into the air, it burns, when ignited, with a small, steady flame, giving out but little light, though producing intense heat. In all cases where hydrogen is burned with oxygen, water is the product. If a cold, dry glass is held over the jet, it is quickly covered with a film of dew, which rapidly increases to drops of water. The gases unite to form steam, which then condenses into the liquid state.

FIG. 158.

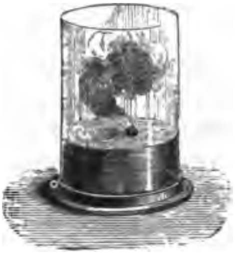


Philosophical Candle.

Oxygen and hydrogen burn quietly when brought cautiously in contact and ignited, but, if the gases are mixed, before ignition, in the proportion of one volume of the first to two of the second, a violent explosion results. Soap-bubbles, if blown with this mixture from a bag and fired with a candle, detonate like a pistol (Fig. 125).

**392. Composition.**—Water is a compound of 8 parts by weight of oxygen to 1 of hydrogen, or by bulk 1 of oxygen to 2 of hydrogen. Its composition may be proved in many ways, but one of the most simple is to throw a little metallic potassium upon its surface. The metal instantly decomposes it, seizing upon the oxygen, and setting hydrogen free with such violence as to produce the vivid combustion of the latter (Fig. 159); the water seems set on fire.

Fig. 159.



Decomposing Water.

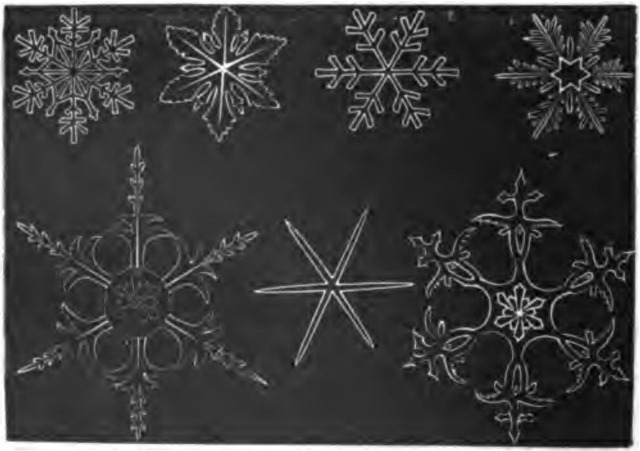
Water is also decomposed by sodium, iron, zinc, and many other metals; in fact, they have been long classified according to their degrees of power in this respect. In numberless operations of chemistry, the elements of water are separated and reunited, and the same thing is going on perpetually in vegetable and animal organisms.

But the composition of water may be shown in the most perfect manner by sending an electric current through a vessel of it (Fig. 62), as already described (141). The gases are set free in the exact proportions given above, and, if mixed together and ignited, they combine with a loud and sharp explosion, the product being pure water. The composition of water is thus demonstrated by both analysis and synthesis.

**393. General Properties.**—Pure water is a transparent, tasteless, inodorous liquid. It is but very slightly condensible—according to Regnault, being compressed 1-47 millionth of its bulk for each atmosphere of pressure—and is perfectly elastic, as it regains its full dimensions when the pressure is removed. It evaporates at all temperatures; boils at 100° C. or 212° F., and freezes at 0° C. or 32° F. It is 815 times heavier than an equal bulk of air. An imperial gallon weighs 70,000 grains, or just 10 lbs. The American standard gallon of pure distilled water at the maximum density weighs 58,972 grains. In thin sheets, water is colorless, but when viewed in thick masses it has a decided tint. Light passed through fifteen feet of pure distilled water emerges of a bright and delicate blue-green, and, by augmenting the thickness, the color is deepened.

**394. Snow Crystals.**—Water, in freezing, crystallizes. The aqueous vapor of the atmosphere, condensed by cold in winter, or at great heights in summer, assumes the most beautiful crystalline forms—those of snow-flakes. Perfect snow-flakes are six-sided stars—modifications of an hexagonal prism—which shoot out an infinity of delicate needles, all diverging from each other at an angle of 60°. These frozen blossoms, as they have been aptly termed, are seen in an endless variety of most exquisite forms, a few of which are shown in Fig. 160.

Fig. 160.



Forms of Snow-Flakes.—(Glaisher.)

When a ray from the sun or an electric lamp is made to pass through a block of pure ice, a portion of the heat is arrested, and must, of course, produce change. As it cannot warm the ice, it melts it. But the ice-particles return to the liquid state in definite order, and, upon examining it with a magnifier, the ice is seen to be filled with beautiful flower-like figures. These consist of water, but as the liquid formed cannot quite fill the space of the melted ice, there occurs a little vacuum, which looks like a globule of burnished silver in the centre of the flower.

**395. Unequal Expansion of Water.**—This liquid contracts as its temperature falls from the boiling-point till it reaches 39° F., when it remains stationary for a time. It then begins to expand, and, in cooling through 7° to the freezing-point, it reaches the same volume it had at 48°. The point of greatest contraction is called the *maximum density* of water. This fact is of great importance in Nature. If water continued to contract as it cooled, it would be denser and heavier at the freezing-point, and, consequently, sink. Lakes and rivers would then begin to freeze at the bottom first, and, in the course of the winter, would become solid masses of ice; while the length of time required to thaw them would greatly prolong the cold season. But as the surface stratum of water approaches the freezing-point and freezes, it expands, and, becoming lighter, floats, and thus the coldest water and ice are kept at the surface, where, as they are almost perfect non-conductors of heat, they protect the mass of water below from the cold above. In freezing, water expands with such power as to burst the strongest vessels. Percolating the minute crevices and fissures of rocks in summer, it freezes in winter, and expands with a force which breaks the solid stones, crumbling them into soil fit for the support of vegetable life.

**396. Its Specific Heat.**—The great specific heat of water is a powerful agency in controlling climate. It is four times greater than that of air; that is, a pound of water, in cooling one degree, would warm four pounds of air one degree. But, as water is 770 times heavier than air, it is obvious that a cubic foot of water, in cooling one degree, would warm four times 770 cubic feet of air, or 3,080 cubic feet one degree. Hence, the vast amount of heat stored up in oceans and lakes, being gradually imparted to the air during winter, modifies the severity of the cold, and explains the fact that island winters are less severe than those of continents or inland places.

The very stability of Nature seems to depend upon this quality of the earth's aqueous element. If the watery masses of the globe, and that large proportion of it contained in our own bodies, lost and acquired heat as promptly as mercury, the variations in temperature would be inconceivably more rapid than now; the inconstant seas would freeze and thaw with the greatest facility, while the slightest changes of weather would send their fatal undulations through all living systems. But now the large amount of heat accumulated in bodies of water during summer is given out at a slow and measured rate; the climate is tempered, and the transitions from heat to cold are gradual and moderated.

**397. Its Solvent Power.**—Water possesses the power of dissolving many solid, liquid, and gaseous substances. This solvent power is variable for different substances, and at different temperatures. Thus, a pound of cold water will dissolve two pounds of sugar, while it will only take up two ounces of common salt, two and a half of alum, or eight grains of lime. Heat generally increases the solvent power of water; thus boiling water will dissolve 17 times as much saltpetre as ice-water. But there are exceptions to this rule; ice-water dissolves twice as much lime as boiling water.

Water dissolves gases in the most diverse proportion, taking up 700 times its bulk of ammonia; its own bulk of carbonic dioxide; $\frac{1}{25}$ its bulk of oxygen, and still less of nitrogen. There is, therefore, an atmosphere diffused throughout all natural waters, which is richer in oxygen than common air, and hence better adapted for supporting the life of aquatic animals. The gases absorbed by water give it a brisk, agreeable flavor, and, if driven off by boiling, the liquid becomes insipid.

**398. Purification of Water.**—Water, as found in Nature, is never perfectly pure, but always contains variable quantities of mineral and organic substances which are either held in suspension mechanically, or are dissolved in it. It is also inhabited by myriads of minute living organisms known as infusoria.

During freezing, the substances dissolved in water are expelled; hence the ice of sea-water (as is well known to sailors), when melted, becomes fresh water. For the same reason, water from melted ice contains neither air nor gas —fish cannot live in it.

**399.** The best method of purifying water is by distillation (111); to render it perfectly pure, it must be redistilled at a low temperature, in silver vessels. By filtration through sand, crushed charcoal, or other closely porous media, water may be deprived of suspended impurities, and of all living beings. Boiling kills all animals and vegetables, expels gases, and precipitates calcic carbonate, which constitutes the *fur* or crust, often seen lining tea-kettles and boilers. Alum (two or three grains to the quart) is often used to cleanse muddy or turbid water, but it does not purify it, being merely decomposed by the calcic carbonate contained in the water, while the alumina set free carries down the impurities mechanically; but the sulphuric acid of the alum, combining with the lime, forms calcic sulphate, and renders the water harder than before. The alkalies, potash, or soda, soften water by decomposing and precipitating the earthy salts; but in their turn remain themselves in solution.

**400. Chemical Properties.**—Although water is neither acid nor alkaline in its action on vegetable colors, it is chemically an exceedingly active body, inducing and undergoing decomposition, when brought in contact with a great number of different substances. When one atom of hydrogen in the water-molecule is replaced by an atom of a positive radicle, it gives rise to a hydrate; when by a negative radicle, to an acid (hydric salt). Water combines directly with many substances, especially those which are crystallizable from aqueous solutions. Thus held in combination, it is termed water of crystallization. From this, it appears that the radicle oxygen contained in water is capable of performing a tetradic linking function, which view may be graphically expressed by assigning to it the formula $H\text{-}\underset{IV}{O}\text{-}H$, instead of $H\text{-}O\text{-}H$.

**401. Hydric Dioxide** ($H_2O_2$) is a transparent, colorless, syrupy liquid, of 1.452 specific gravity, which does not solidify at —30° C., and may be evaporated at low temperatures in a vacuum. It has an astringent taste, a decided odor, and possesses active bleaching properties. It is a very unstable compound, decomposing slowly at 15° C., while higher temperatures, or the contact of various substances, causes it to separate into water and oxygen with explosive violence. It may be regarded as free hydroxyl (HO), composed of two atoms of a compound monad radical.

## § 2. *The Atmosphere.*

**402. Its Composition.**—It was not until the year 1774 that Lavoisier pointed out the true composition of the atmosphere. Up to this time it was spoken of as one of the four elements; but the careful observations of Priestley and Scheele, and their discovery of oxygen gas, prepared the way for a knowledge of its exact composition. It is now regarded as a mixture of several gases, nitrogen and oxygen constituting its bulk—the one incapable of supporting combustion or respiration, and the other essential to life.

| Air contains, | Composition by Volume. | Composition by Weight. |
|---|---|---|
| Oxygen, | 20.96 | 23.185 |
| Nitrogen, | 79.04 | 76.815 |
| | 100.00 | 100.000 |

That the air is made up of these gases may be ascertained both by analysis and synthesis. That it is a mixture and not a chemical compound is made manifest by the facts that its components are not united in the ratio of their atomic weights, and that each gas dissolves in water, independently of the other; but the analyses of air collected from different parts of the earth, and at different heights, show a remarkable uniformity in its composition. In addition to the oxygen and nitrogen present in the atmosphere, there is always a small proportion of aqueous vopor, carbonic dioxide, and ammonia.

**403.** The proportion of watery vapor in the atmosphere varies with the temperature. It usually ranges from the $\frac{1}{60}$ to the $\frac{1}{200}$ of the bulk of the air. By passing known quantities of air through carefully-weighed tubes of potassic hydrate, the carbonic dioxide is absorbed, and its proportion determined. It varies from 3 to 6 parts in 10,000 of air, and averages about one volume in 2,500. The quantity is variable within the limits above stated. It increases as we rise from the earth, and is less after a rain, which washes it down from the air; it increases during the night, and diminishes after sunrise, is less over large bodies of water than over large tracts of land, and is more abundant in the air of towns than in that of the country.

**404. The Carbonic Acid** which is poured into the atmosphere in prodigious quantities and from innumerable sources, is as necessary to the vegetable world, as is oxygen to the animal world. It is absorbed by the leaves, and minute as is its proportion, if it were withdrawn, the vegetable world would quickly perish. Liebig has shown that the air contains minute traces of ammonia, which are washed down, and may be detected in rain-water. Traces of nitric acid have also been frequently detected. This substance is thought to be formed by electricity, every flash of lighting which darts across the sky combining a portion of the oxygen and nitrogen along the line of its course, and forming this acid. The saline particles of the ocean-waves, as they are dashed into foam and spray, are carried by the winds far inland. All these substances are brought down by the rains, and help to quicken the growth of vegetation.

**405. Resulting Properties.**—Each of the constituents of the air is essential to the present order of things. Oxygen is preëminently its active element. To duly restrain this activity, the oxygen is diluted and weakened by four times its bulk of the negative element, nitrogen. Their properties are thus perfectly adjusted to the requirements of the living world. Were the atmosphere wholly composed of nitrogen, life could never have been possible; were it to consist wholly of oxygen, other conditions remaining as they are, the world would run through its career with fearful rapidity; combustion once excited, would proceed with ungovernable violence; animals would live with hundred-fold intensity, and perish in a few hours.

**406. The Atmosphere and the Living World.**—The relations of the atmosphere to living beings, the stability of its composition, and the wonderful forces that are displayed within it, are full of surpassing interest. The vegetable world is derived from the air; it consists of condensed gases that have been reduced from the atmosphere to the solid form by solar agency. On the other hand, animals, which derive all the material of their structure from plants, destroy these substances while living, by respiration, and when dead, by putrefaction, thus returning them again in the gaseous form to the air whence they came.

# CHAPTER XVII.

## THE SULPHUR GROUP.—SULPHUR, SELENIUM, TELLURIUM.

### § 1. *Sulphur and its Compounds.*

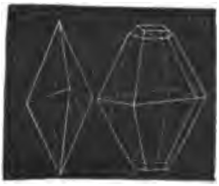
SULPHUR.—Symbol, S. Atomic Weight, 32; Quantivalence, II, IV., VI.; Molecular Weight, 64; Molecular Volume, 2; Specific Gravity, 2.05.

**407. Modifications of Sulphur.**—Sulphur, like oxygen, is capable of existing in several different modifications. At ordinary temperatures it is solid, or nearly so. At 115° C., it melts to a pale-yellow liquid. As the temperature rises this liquid becomes viscid, until, between 200° and 250° C., it is too thick to flow. At a still higher temperature it again becomes fluid, and finally boils at 440° C. The density of the vapor then diminishes gradually, until, at 1000° C., a point is reached where it is 32 times as great as that of hydrogen at the same temperature. Sulphur in all its forms is insoluble in water and alcohol, a poor conductor of heat, and a non-conductor of electricity. When heated in the air to 260° C., it takes fire, burning with a pale-blue flame. The vapor of sulphur supports combustion, many metals taking fire in it, and burning actively. When combined with metals or positive radicals, sulphur is a dyad, but in other combinations it may be either a tetrad or hexad.

**408. Ordinary Modification** ($S_\alpha$)—In this form, sulphur is one of the oldest known substances, being mentioned in the Bible, and in the writings of the ancients. It exists abundantly in Nature; is found in various volcanic regions, as in the island of Sicily, where it is mined in immense quantities for the market. It is deposited by many springs and small lakes, being produced by the decomposition of hydric sulphide. The sulphur of commerce is prepared from the impure native material, by subjecting it to a rough distillation in earthen retorts which separates it from mineral impurities. It is also obtained from a native ferric sulphide. This is generally done by piling the ferric sulphide with wood, in large heaps in the open air, and setting these on fire. A portion of the ferric sulphide burns, and, through the heat attending its combustion, the remainder is also decomposed with the liberation of sulphur, which volatalizes and collects in the fluid state, in basin-shaped cavities on the surface of the heap. In commerce, sulphur exists in forms due to the different modes of its preparation: first, as *roll-sulphur or brimstone*, obtained by running melted sulphur into moulds; second, as *flour of sulphur*, a pale yellow gritty powder, obtained by sublimation; and, third, as *milk of sulphur*, produced by the decomposition of solutions of certain sodic and potassic sulphides with acids.

**409. Properties.**—In its ordinary modification sulphur is a brittle, yellow solid, crystallizing in transparent right rhombic octohedra, or allied forms (Fig. 161). It is soluble in carbonic disulphide, and the crystals may be obtained from this solution by evaporation.

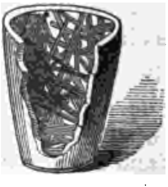
FIG. 161



Sulphur-Crystals.

**410. Oblique Prismatic Sulphur** ($S_\beta$).—This modification may be obtained by melting ordinary sulphur in a crucible, allowing it to cool until a crust is formed, then breaking the crust and pouring out the still fluid portion. The walls of the crucible will then be found lined with a mass of transparent yellowish-brown, needle-shaped crystals (Fig. 162). They are oblique rhombic prisms, or modifications of these, have a specific gravity of 1.98, and in the course of a few days pass spontaneously into the ordinary octahedral modification. They are readily soluble in carbonic disulphide.

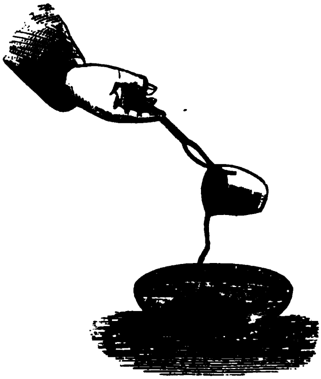
FIG. 162.



Crystals by Fusion.

**411. Plastic Sulphur** ($S\gamma$). — This variety is produced by heating melted sulphur to a temperature of from 260° to 300° C., and then suddenly cooling it by pouring it in a thin stream into water (Fig. 163). It is a dark-brown tenacious mass, which may be drawn into threads like India-rubber. It has a specific gravity of 1.95, and is insoluble in carbonic disulphide. It gradually changes to the ordinary modification. Sulphur is consumed largely in the manufacture of hydric sulphate, of gunpowder, and of friction-matches. Milk of sulphur is extensively used in medicine. The plastic modification is often employed to take impressions of medals, coins, and similar objects.

Fig. 163.



Amorphous Sulphur.

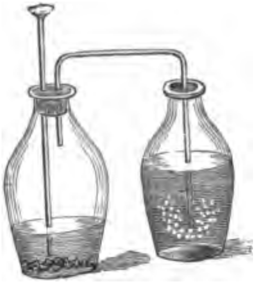
**412. Hydric Sulphide** ($H_2S$) (*Sulphuretted Hydrogen*).—Hydric sulphide was discovered by Scheele, in 1777. It is found abundantly in Nature as a volcanic product, as the essential ingredient to which the waters of so-called sulphur-springs owe their flavor, and as one of the bodies resulting from the decay of organic matter.

**413. Preparation and Properties.**—It is usually obtained by the action of dilute hydric sulphate on ferrous monosulphide.

$$Fe''S + H_2SO_4 = Fe''SO_4 + H_2S$$

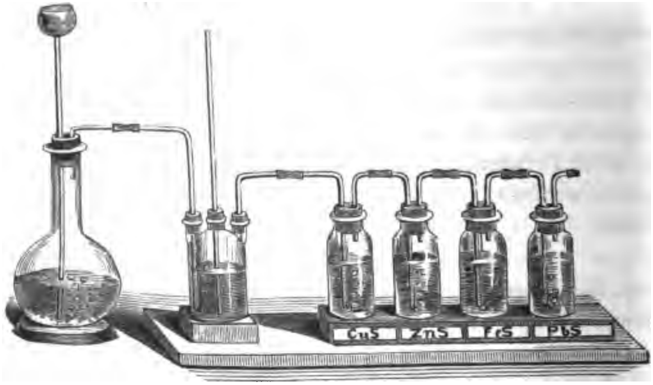
Fig. 164 represents a convenient arrangement for its evolution. The ferric monosulphide should be broken into small lumps and placed in the flask. The cork and tubes may then be adjusted, and, first, water, and then hydric sulphate poured in through the funnel-tube. The gas is absorbed by the water of the second vessel. The solution must be kept in tightly-secured bottles, as, if exposed to the air, it is gradually decomposed. Hydric sulphide is a colorless transparent gas, having the well-known odor of rotten eggs. Cooled to 74°, or submitted to a pressure of 17 atmospheres at 10°, it condenses to a colorless mobile liquid of 0.9 specific gravity, which freezes at −85°, the frozen portion sinking in the liquid. It readily dissolves in water, imparting to the solution its taste and smell. Its reaction on vegetable colors is slightly acid, and heated in the air it burns with a pale-blue flame. When breathed it is highly poisonous, and even when much diluted with air it has proved fatal to many of the lower animals. Hydric sulphide is used extensively in chemical operations as a re-agent. Its action upon solutions of the metals may be shown by the apparatus represented in the accompanying cut (Fig. 165). The gas is evolved from ferrous sulphide in a two-necked bottle, and passed through

Fig. 164.



Liberation of Hydric Sulphide.

Fig. 165.



Precipitation of Metals by Hydric Sulphide.

a second bottle containing a little water, after which it successively passes through bottles containing solutions of cupric sulphate, zinc sulphate, ferrous sulphate, and lead sulphate. The cupric sulphate in the first bottle will give a black precipitate, that in the second a white, while the last ones yield black precipitates.

**414. Chloric Disulphide**, $Cl_2S_2$.—This compound, more generally termed chloride of sulphur, is obtained by passing dry chloric gas over melted sulphur. It is a deep orange-yellow liquid of peculiar disagreeable odor, boiling at 136° C. It is instantly decomposed by water. Chloric disulphide is employed in the vulcanization of caoutchouc.

**415. Sulphur and Oxygen.**—Sulphur may unite with oxygen as a dyad, tetrad, or hexad. The following are the oxides and acids with which we are acquainted:

| | | | |
|---|---|---|---|
| Sulphurous oxide, | $S^{IV}O_2$. | Sulphurous acid, | $H_2S^{IV}O_3$. |
| Sulphuric " | $S^{VI}O_3$. | Sulphuric " | $H_2S^{VI}O_4$. |

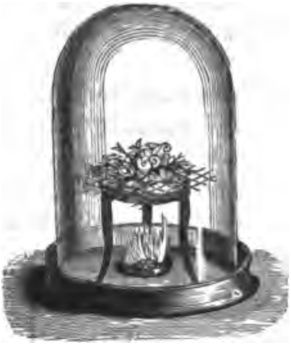
**416. Sulphurous Oxide**, $SO_2$.—This substance occurs among the products of volcanic action, and is always formed by the combustion of sulphur in air, or in pure oxygen, thus:

$$S_2+O_4=2(SO_2)$$

It is a transparent, colorless gas, of 2.25 specific gravity, having a pungent, suffocating odor, familiarly known in the case of a burning match. It extinguishes combustion; hence sulphur is often thrown into the fire to quench the burning soot of chimneys. It has a strong attraction for water. Allowed to escape into the air, it forms white fumes with its moisture, and a piece of ice thrust into the gas is instantly liquefied. Water at 60° F. takes up large quantities of this acid, the solution formed having the taste and smell of the gas. By cold or pressure it condenses into a liquid, of 1.49 specific gravity, which evaporates so fast that the cold generated will freeze water even in a red-hot crucible. At −76° C. it becomes solid.

**417. Uses.**—Sulphurous oxide is used as a disinfectant, and in bleaching woolen and straw fabrics. The goods are moistened, and suspended in large chambers, or, in a small way, they are put into inverted barrels, and exposed to the fumes of burning sulphur. The effect is produced, not by destroying the coloring matter, as in the case of chlorine, but by the union of the acid *with* the coloring matter, which forms a white compound. If a red rose is held over burning sulphur, it is whitened, but the color is at once restored by weak sulphuric acid, which, being stronger, discharges sulphurous oxide from combination. The bleaching power of sulphurous oxide upon flowers may be illustrated by burning sulphur under a glass, within which are some highly-colored flowers. (Fig. 166.) If woolens, after sulphur-bleaching, are washed with a strong alkaline soap, the acid is neutralized by the alkali, the coloring matter liberated, and the yellowish color restored.

Fig. 166.



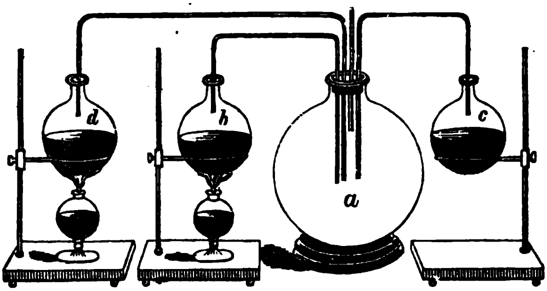
Bleaching by Sulphurous Oxide.

**418. Sulphurous Acid, Hydric Sulphite,** $H_2SO_3$.—The solution of sulphurous oxide in water contains a definite compound of the form $H_2SO_3$, which is possessed of strong acid properties. It is sometimes used for the same purposes for which sulphurous oxide is employed. The hydrogen in this compound is replaceable wholly or in part by metallic elements, giving rise to numerous salts known collectively as sulphites.

**419. Sulphuric Oxide,** $SO_3$.—This may be obtained in the form of a white snowy solid, by heating disulphuric acid, and collecting the fumes which pass over into a receiver surrounded by a freezing mixture. While in this condition, it exhibits no acid properties, and may be handled with impunity, if the hands are dry. But it fumes in the air, and rapidly absorbs moisture. When thrown into water it hisses like a hot iron, and the solution thus formed possesses all the properties of the ordinary acid.

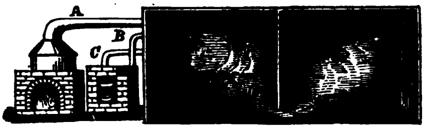
**420. Sulphuric Acid, Hydric Sulphate,** $H_2SO_4$.—This important chemical compound was known as early as the fifteenth century. It is found native in a dilute condition, in volcanic regions, and in the waters of some springs and rivers. Sulphuric acid may be prepared on a small scale in an apparatus represented by Fig. 167. A large glass balloon, *a*, is connected by tubes with three flasks. Flask *b* supplies it with sulphurous oxide; *c*, with nitric dioxide; *d*, with steam, and the short tube furnishes air. These four substances react upon each other with the continued production of sulphuric acid. In the manufactory the balloon is represented by large chambers lined with sheet-lead, and the flasks by furnaces (Fig. 168). In one furnace sulphur is heated,

FIG. 167.



Preparation of Sulphuric Acid.

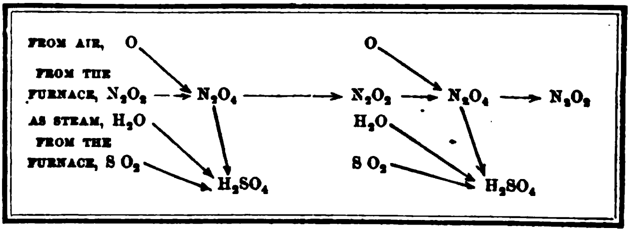
FIG. 168.



Liberating Sulphuric Acid.

and pours into the chamber sulphurous oxide, $SO_2$. In another nitre is heated in an iron pot with sulphuric acid, by which fumes of nitric acid, $HNO_3$, are produced and delivered into the chamber. The $HNO_3$ is quickly deprived of an atom of oxygen by the sulphur, yielding water and nitrogen tetroxide, $N_2O_4$. Steam and air are thrown into the chamber by another flue, and thus the conditions of action are secured.

**421.** The process depends upon the property possessed by the higher oxides of nitrogen of oxidizing sulphurous oxide, at the expense of the oxygen of the atmosphere. The sulphurous oxide is converted into the sulphuric, the oxygen being derived from the air, and the nitric dioxide being the carrier that transports it. A small quantity of $N_2O_3$ may thus form an endless quantity of $SO_3$, which unites with the water present to form sulphuric acid, $H_2SO_4$. These changes are represented in the following scheme:



The large chambers of the manufactory are divided by leaden partitions with narrow openings, which serve to facilitate the intermixture of the gases as they pass on through the apartments. The bottom of the chamber is always kept covered with water to the depth of two or three inches, to absorb the acid as it falls. When the water has acquired a density of 1.5, by the absorption of acid, it is drawn off and boiled down in glass or platinum retorts, until it has a specific gravity of about 1.8. The acid thus obtained has the formula $H_2SO_4$, and constitutes the ordinary sulphuric acid of commerce.

**422. Properties.**—Sulphuric acid is a thick, oily liquid of 1.85 specific gravity, without odor, and has at first a soapy feel, but it speedily corrodes the skin, causing an intense burning sensation. It is the most powerful of acids, and has an intense affinity for water. When a splinter of wood is dipped into it for a short time, it turns black, the acid taking away from it the elements of water, and leaving the carbon. In like manner, it decomposes and chars the skin and most other organic substances by removing their water. If a little concentrated acid is exposed to the open air in a shallow dish it will soon double its weight from the moisture absorbed. When sulphuric acid and water are mixed they shrink in bulk, and heat is produced. A mixture of four parts concentrated acid to one part water (Fig. 169) evolves sufficient heat to boil the ether in a test-tube. The concentrated acid freezes at about – 30° F., and boils at 640° F. Pure sulphuric acid is colorless, but slight traces of organic matter, as dust or straws, turn it of the dark shade usually seen in commerce. The commercial acid is cheap, but impure, containing traces of lead, arsenic, potash, hydric chloride, and sulphurous oxide. The test for sulphuric acid is a solution of baric chloride (440).

Fig. 169.

Boiling Ether.

**423. Uses.**—Sulphuric acid is the most important substance used in manufactures. It is employed to make sodic and chloric carbonate, citric, tartaric, acetic, and nitric acids, sodic and magnesic sulphate, and various paints; also, in dyeing, calico-printing, gold and silver refining, and in purifying oil and tallow. Its chemical uses are innumerable. *Disulphuric acid*, $H_2S_2O_7$, is also known as *Nordhausen* sulphuric acid, or *fuming* sulphuric acid, and is manufactured by the original process—the distillation of dried ferrous sulphate in earthen retorts. It is a heavy, oily liquid, of 1.9 specific gravity, fuming strongly in contact with the air. Heat decomposes it into sulphuric acid and sulphuric oxide. The method by which this acid is obtained from ferrous sulphate, or "green vitriol," has given rise to the name of "oil of vitriol," by which sulphuric acid is generally known.

## § 2. *Selenium and Tellurium.*

**424. History.**—Selenium and Tellurium are elements closely allied to sulphur. They form compounds with dry hydrogen, $H_2Se$, and $H_2Te$, similar to $H_2S$; and also compounds with oxygen and hydrogen, resembling sulphurous and sulphuric acids. Selenium is a rare substance, existing in several modifications, apparently analogous to those of sulphur. Its name is derived from a Greek word, meaning *the moon.* At ordinary temperatures it is a solid of a brownish-red color, and with a lustre somewhat resembling that of the metals. Selenium boils at 700° C. Heated in the air it burns, emitting an intolerable odor resembling decayed horse-radish. Tellurium was first distinguished in 1798, by Klaproth, who named it tellurium, from the Latin "tellus," *the earth.* It is found in Nature, but is exceedingly rare. It is a tin-white brittle metal, crystallizing in rhombohedrons, melting at about 500° C., and volatilizing at a white heat. Heated in the air it takes fire, and burns with a lively blue flame, edged with green. The vapor of tellurium has a greenish-yellow color.

# CHAPTER XVIII.

## COPPER AND MERCURY.

### § 1. *Copper and its Compounds.*

**COPPER.—Symbol, Cu. Atomic Weight, 63.5; Quantivalence, II.; Specific Gravity, 8.9.**

**425. Copper.**—This metal, well known since earliest times, is often found native in masses of considerable magnitude. It is obtained on a large scale by the decomposition of ores, of which copper pyrites ($Cu_2Fe_2S_4$), cuprous oxide ($Cu_2O$), and malachite ($Cu_2H_2CO_5$), are among the most important. The processes of its extraction are very complicated. ***Metallic copper*** is tough, malleable, and of a red color. The metal may be stiffened by hammering, and softened by heating and suddenly cooling in water; the reverse of the effect produced upon steel. In dry air it is hardly acted upon, but in a damp atmosphere it acquires a green crust of a cupric carbonate familiarly known as *verdigris.* Copper is an excellent conductor of heat and electricity, and is extensively used for telegraph-wires. Being little affected by the air, it is better adapted for culinary utensils than iron. Vegetable acids, however, dissolve it in the cold state; hence sauces containing vinegar, and preserved fruits or jellies, should not be allowed to remain in copper vessels, as the salts produced are poisonous. Copper forms alloys with other metals, among which may be mentioned brass, German-silver, bronze and speculum metal.

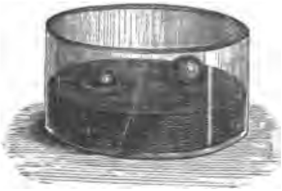
**426. Cupric Oxide,** CuO.—This oxide is found native as the mineral melaconite. It may be artificially prepared by strongly heating cupric nitrate ($CuN_2O_6+3H_2O$). It is a black or brownish-black powder, fusible at red-heat. It is used in organic analysis as a source of oxygen, and in the manufacture of glass and porcelain to impart a green color. *Cupric sulphate* (*Blue Vitriol*), ($CuSO_4 + 5H_2O$), is obtained by heating cupric sulphide in contact with air, or by the action of sulphuric acid on metallic copper. It is used largely in dyeing and calico-printing, and as a source of many of the pigments containing copper. *Cupric arsenite*, or Scheele's green, is obtained by mixing solutions of cupric sulphate with sodic arsenite. It is of bright-green color, exceedingly poisonous, and is used as a pigment. In commerce it is called Paris green.

## § 2. *Mercury and its Compounds.*

MERCURY.—Symbol, Hg. (Hydrargyrum). Atomic Weight, 200; Quantivalence, II.; Molecular Weight, 200; Molecular Volume, 2; Specific Gravity, 13.59.

**427. History.**—This remarkable element is often found native in little globules, disseminated through certain ores, particularly cinnabar, or mercuric sulphide (HgS). It is obtained on a large scale by distillation of the cinnabar-ore, either alone or mixed with burnt lime or forge-scales. Mercury has a silver-white color, and a brilliant lustre, and is remarkable in being a liquid at ordinary temperatures. Its specific gravity is nearly twice that of iron, a ball of which will sink half-way into the liquid mercury, while wood will float upon its surface (Fig. 170).

FIG. 170.



Ball sinking in Liquid.

It solidifies when cooled to -40° C., and is then soft and malleable, but if reduced to a much lower temperature it becomes brittle. It boils at about 350° C., and slowly volatilizes at all temperatures above 15° C. Metallic mercury is used extensively in the manufacture of philosophical instruments, thermometers, barometers, and to form an alloy with tin for coating the backs of mirrors. It is also used largely in the extraction of gold and silver by the process of amalgamation. The alloys of mercury are called amalgams.

**428. Mercuric Oxide,** $HgO$.—This substance, commonly known as *red oxide of mercury*, or *red precipitate*, may be formed by heating metallic mercury up to 600° F., with free access of air. A still higher heat decomposes it, liberating the oxygen, and reducing the mercury to the metallic state. This oxide furnishes a ready source of oxygen gas, being the compound from which oxygen was first obtained by Priestley, and by which Lavoisier proved the composition of air.

**429. Mercuric Chloride,** $HgCl_2$ (*Corrosive Sublimate*). —This compound is prepared by mixing mercuric sulphate, $HgSO_4$, with an equal weight of common salt, and applying heat to the mixture. It is soluble in water and in alcohol. Its solution has a metallic, acrid taste, and an acid reaction. It is a deadly poison, and accidents have occurred from its substitution for calomel. The proper antidote for it is white of egg, which forms with it an insoluble inert compound. This substance is used in a process for preserving wood, by impregnation with its solution, which is termed *kyanizing*.

**430. Mercurous Chloride** (*Calomel*), $Hg_2Cl_2$. — This compound is found native as "*horn quicksilver.*" It is prepared by triturating mercuric chloride, $HgCl_2$, with mercury, or is precipitated whenever solutions of any mercurous compounds and a soluble chloride are mixed together. Sublimed calomel is a crystalline powder, white or dirty white in color; very heavy, tasteless, and inodorous. Calomel is decomposed by light. It has been very extensively used in medicine, and is much less poisonous than "corrosive sublimate."

**431. Mercuric Sulphide** (Cinnabar), $HgS$, occurs in large beds at Almaden, in Spain, and is also found in extensive deposits in California. It is produced in considerable quantity by artificial means, and sold as a pigment under the name of *vermilion.*

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## CHAPTER XIX.

### THE CALCIUM GROUP—CALCIUM, STRONTIUM, BARIUM, LEAD.

### § 1. *Calcium and its Compounds.*

CALCIUM.—Symbol, Ca. Atomic Weight, 40; Quantivalence, II. and IV.; Specific Gravity, 1.57.

**432. History.**—Calcium is one of the most abundant constituents of the crust of the earth. It occurs in the extensive layers of limestone, marble, and chalk, as a carbonate. In gypsum and alabaster it is found as a sulphate, while as a phosphate it forms an important constituent of the bones of animals. The metal itself is rare, and is prepared by passing a galvanic current through fused calcic chloride. It is a light-yellow metal, somewhat harder than lead, very malleable, melts at a red heat, and oxidizes in the air.

**433. Calcic Oxide,** $CaO$ (*Lime*).—This well-known substance does not occur in Nature, but is prepared by burning calcic carbonate, limestone ($CaCO_3$), in large masses in kilns. The carbonic dioxide is driven off by the heat, and a white, stony substance remains, called *quick*-lime, or *caustic* lime. One ton of good limestone yields 11 cwt. of lime. When this is exposed to the air it first rapidly imbibes moisture and crumbles to powder. This gradually absorbs carbonic dioxide, and, becoming less and less caustic, regains the neutral condition of the carbonate.

**434. Calcic Hydrate.**—When water is poured upon quicklime it absorbs it (every 28 lbs. of lime taking nine pounds of water), swells to thrice its original bulk, crumbles to a fine white powder, and is converted into calcic hydrate, $CaH_2O_2$. This process is called *slacking*, and sufficient heat is often produced by the chemical action to ignite wood. *Lime-water* is a saturated, transparent solution of calcic hydrate in water. *Cream* or *milk of lime* is a thick mixture of the hydrate with water, such as is used in whitewashing. In tanneries the hides are immersed in milk of lime, which partially decomposes them, so that the hair may be easily removed. *Calcic hydrate* exhibits the properties of a strong alkali, decomposing organic tissues and saturating the strongest acids. It is more soluble in cold than in hot water. Hence, when cold saturated lime-water is boiled, a portion of the hydrate is deposited. Slacked lime is extensively used in chemical manufactures, and as a fertilizer. Its value as a fertilizer is due to the property which it has of decomposing organic and inorganic constituents of soil.

**435. Mortar and Cement.**—Lime, mixed with sand, forms the mortar employed by builders to cement stones and bricks. To make the best mortar, the lime should be perfectly caustic and the sand sharp and cross-grained. The nature of the changes by which the mortar becomes hardened is not satisfactorily explained. It is supposed to be owing in part to the absorption of carbonic dioxide from the air by the lime, and the subsequent hardening into a calcic carbonate. In time the lime also partially combines with the silica of the sand, forming an exceedingly hard silicate of lime. Common mortar, when laid in water, not only refuses to harden, but its lime gradually becomes dissolved out and washed away. *Hydraulic cement* possesses the property of solidifying under water. This quality is owing to the presence of clay (aluminic silicate) in the lime of which it is composed.

**436. Bleaching-Powder.**—When chlorine is passed through recently-slacked lime, large quantities of the gas are absorbed, forming the *bleaching-powder* of commerce. The chemical constitution of this substance is yet a matter of doubt. It is generally regarded as a mixture of calcic hypochlorite with calcic chloride, but it is not impossible that it may correspond to the graphic expression Cl–Ca–O–Cl. It is a white, sparingly soluble powder, used in great quantities for bleaching purposes. In the bleaching of cotton fabrics, the goods are first freed from all greasy impurities, and then digested in a solution of this powder. They are next dipped into very dilute sulphuric acid, by which chlorine is liberated, and exerts its bleaching power. This process requires to be repeated several times before the color is entirely discharged; after which the goods are thoroughly washed in water, in order to remove all trace of acid from the fibre of the cloth.

**437. Calcic Sulphate,** $CaSO_4$.—This salt occurs native as the mineral anhydrite, and is produced artificially on a large scale by calcining powdered gypsum ($CaSO_4 + 2H_2O$), at about 250° C. Thus prepared it constitutes "plaster of Paris," and possesses the property of combining with water when made into a paste. It is used for taking casts by running the mixture into hollow moulds, and colored and mixed with glue, for producing the ornamental designs known as stucco-work. *Calcic sulphate dihydrate* (*gypsum, alabaster*), $CaSO_4 + 2H_2O$, occurs in many parts of the world, forming extensive rocky beds. In its pure, transparent form, it is known as *selenite*, and in its compact and earthy varieties as gypsum and alabaster. Gypsum is used extensively as a fertilizer.

**438. Calcic Carbonate,** $CaCO_3$.—Vast deposits of this substance are distributed all over the globe in the form of limestones, marbles, chalks, marls, coralreefs, shells, etc. Numerous and extensive as are these deposits, it is conjectured that they are all of animal origin. The densest limestone and the softest chalk are found to consist of the aggregated skeletons or shells of myriads of tribes of the lower animals, which have existed in some former period of the world's history. The formation of coral-reefs, which are sea-islands of calcic carbonate, built up from the depths of the ocean by minute aquatic animals, is an example of similar deposits now in process of formation. Calcic carbonate is decomposed by heat into calcic oxide and carbonic dioxide. *Hydro-calcic carbonate*, $CaH_2C_2O_6$. When calcic carbonate is acted upon by water containing carbonic dioxide in solution, it dissolves with the formation of this compound. This solution, naturally formed, constitutes one of the varieties of hard water, which is generally met with in limestone districts.

**439. Calcic Phosphate,** $Ca_3 (PO_4)_2$.—This is the earthy constituent of the bones of animals. They obtain it from the plants, and the plants in turn take it from the soil. It is found abundantly in the grains of cereals, which, as the supply is limited in the soil, rapidly exhaust it, when they are cultivated, year after year; hence the importance of restoring to the land the phosphates when they are removed by the crops.

## § 2. *Strontium and Barium.*

**440. Strontium**—Resembles calcium, both in appearance and properties. It is obtained from its chloride, and is a pale-yellow metal, of specific gravity 2.54. It does not change in dry air, but decomposes water readily, evolving hydrogen. *Barium* is a light-yellow metal, which rapidly oxidizes in the air, decomposes water, and has a specific gravity of 4.0. The compounds of these elements, though less widely distributed, are allied to the corresponding compounds of calcium. The *nitrate of strontium* is used in pyrotechny, and imparts to flame a beautiful crimson color. *Baric oxide*, or *baryta* (BaO), is a gray powder having a strong attraction for water, which it absorbs on exposure to the air, forming baric hydrate. *Baric chloride dihydrate* ($BaCl_2+2H_2O$) is interesting chiefly as the usual test for sulphuric acid, with which it gives a dense, white, insoluble precipitate of baric sulphate. It has been employed in medicine. *Baric sulphate*, or *heavy spar*, occurs in large quantities, and when ground is extensively consumed under the name of barytes, in the adulteration of paints.

## § 3. *Lead and its Compounds.*

LEAD.—Symbol, Pb. (Plumbum). Atomic Weight, 207; Quantivalence, II. and IV.; Specific Gravity, 11.44.

**441. Lead.**—This useful and common metal is of doubtful native occurrence, but is obtained from various ores, of which the mineral galena, a plumbic sulphide, is the most important. Lead is a soft, blue metal, easily scratched by the nail, and leaving a stain when rubbed upon paper. It is highly malleable, but not very ductile. In the air a film of oxide rapidly forms on its surface, which protects it from further corrosion. It melts at about 330° C., and on solidifying contracts to such an extent as to render it unfit for castings. Lead is much used in the manufacture of pipe for conducting drinking-water to the different parts of dwellings.

If lead is exposed to the combined action of pure water and air, plumbic hydrate is formed on the exposed surface, which is dissolved by the water with which it is in contact. This solution of plumbic hydrate absorbs carbonic dioxide with formation of plumbic carbonate, a highly-poisonous compound. The presence of chlorides or nitrates assists this corroding action, while it is retarded by the sulphates, phosphates, or carbonates. Hydro-calcic carbonate, a salt found in many spring-waters, also prevents this corrosion by depositing a coating on the exposed surface. As all lead-salts are poisonous, it is not safe to use water which has been kept in cisterns lined with lead, or which has been conveyed through lead pipes, unless it has been carefully ascertained that the water contains such foreign matters as will prevent its action upon the metal. Lead in the presence of air and moisture is acted upon by feeble acids. Hence the use of vessels made of lead should be carefully avoided in the culinary department. This metal is extensively used in the arts, both alone and alloyed with other metals. An alloy prepared by mixing 2 parts of arsenic with 100 parts of lead is employed in the manufacture of shot.

**442. Plumbic Monoxide,** $Pb^{II}O$. — This substance is found native as lead-ochre, a yellow massive mineral of crystalline structure. It is obtained on a large scale by heating lead to a point a little below redness, or in the process of cupellation. The former product is known as *massicot*, the latter as *litharge.* Plumbic monoxide is met with in several isomeric modifications, as a yellow or red crystalline substance, or as an amorphous powder. At a red-heat plumbic monoxide melts to a clear, dark-red liquid. In water it is slightly soluble with formation of lead hydrate. Acids dissolve it readily, giving rise to plumbic salts. It is much used in glass-making, and in glazing earthen-ware. *Triplumbic tetroxide* ($Pb_3O_4$), (minium or red lead), occurs native, and is formed when plumbic monoxide is for some time exposed to a low red heat in contact with air. It is extensively used as a pigment, and in the manufacture of flint-glass.

**443. Plumbic Carbonate,** $PbCO_3$, *White Lead.*—This salt it found beautifully crystallized in Nature, but it is largely manufactured as a paint. It is produced in several ways, but the following, which is known as the Dutch method, is considered the best: Thin sheets of lead, rolled up into loose scrolls, are placed in earthen pots with weak vinegar or acetic acid. Thousands of these pots, fitted with lead covers and closely packed, are then buried in spent tan-bark. The acetic acid corrodes the metal, forming a superficial coating of plumbic acetate, and the carbon dioxide set free by the decomposing vegetable matter decomposes the acetate with formation of plumbic carbonate and free acetic acid. The acetic acid attacks more metal, which is again converted into carbonate; and thus, with a small charge of vinegar, the operation is continued a long time, and a large quantity of lead changed. White lead is extensively adulterated with baric sulphate; it may be detected by adding nitric acid, which dissolves the lead, leaving the baric sulphate as an insoluble residue.

**444. Plumbic Acetate,** $Pb\ (C_2H_3O_2)_2$. This important salt of lead is easily procured by dissolving plumbic monoxide (PbO) in acetic acid. It receives its common name "sugar of lead" from its sweet taste, and its general likeness, in appearance, to loaf-sugar. It is exceedingly poisonous. The soluble salts of lead are most of them colorless, and redden litmus-paper. Metallic lead is easily precipitated from solutions of its salts by means of iron or zinc.

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# CHAPTER XX.

## MAGNESIUM GROUP—MAGNESIUM, ZINC, CADMIUM.

### § 1. *Magnesium and its Compounds.*

MAGNESIUM.—Symbol, Mg. Atomic Weight, 24; Quantivalence, II.; Specific Gravity, 1.74.

**445. History and Occurrence.**—This metal was first obtained by Davy, in 1808. It does not occur native, but may be obtained by decomposing magnesic chloride by metallic sodium. Magnesium is a white or bluish-gray crystalline metal; malleable and ductile, melts at a moderate red-heat, and volatilizes at higher temperatures.

Heated in the air it burns with a dazzling bluish-white light, and is on this account much used for signaling, and, as a source of artificial light in photography.

**446. Magnesic Oxide**, MgO, *Magnesia.*—This compound is obtained by strongly heating magnesic carbonate. It is a white, light powder, with feeble alkaline properties, very sparingly soluble in water, but dissolving readily in acids. It is found native as the mineral periclase. It is used principally in medicine as a mild aperient and antacid. *Magnesic Sulphate*, Mg $SO_4+7H_2O$ (*Epsom Salts*), is a common ingredient of mineral waters, and takes its name from the circumstance of its being contained in great quantities in the springs near Epsom, in England. The commercial supply is chiefly derived from sea-water, by decomposing the magnesic compounds with lime, and then adding sulphuric acid. It may also be obtained from magnesian limestone. It is soluble in water, has a bitter, saline taste, and is used in medicine as a cathartic and an antidote to various poisons. It has also been used as a fertilizer.

## § 2. *Zinc and Cadmium.*

ZINC.—Symbol, Zn. Atomic Weight, 65; Quantivalence, II.; Molecular Weight, 65; Molecular Volume, 2; Specific Gravity, 7.0.

**447. History and Occurrence.**—This element is not found native, but is obtained on a very extensive scale by the decomposition of certain ores, among which zincic sulphide or "blende" (ZnS), zincic carbonate ($ZnCO_3$), zincic oxide (ZnO), and a zincic silicate, are the most important. It is a brilliant, bluish-white metal. At common temperatures it is brittle, but, when heated from 212° to 300° F., it may be rolled out into thin sheets, and retains its malleability when cold. At 400° it again becomes quite brittle; at 770° it melts, and at a red heat volatilizes. When strongly heated in the air it takes fire, burning with a whitish-green flame and production of zincic oxide. Zinc soon tarnishes in a moist atmosphere, forming a thin film of oxide, which resists further change. This property renders it useful for a variety of purposes, such as for gas-pipes, gutters, roofing, and for galvanizing iron, thus preventing it from oxidation. It is also used in the preparation of hydrogen gas.

**448. Zincic Oxide**, ZnO.—This compound is found when zinc is burned with free access of air. It is a fine white powder, familiarly known as zinc white. It is largely used as a paint. *Zincic Chloride*, $ZnCl_2$, may be prepared by distilling an intimate mixture of zincic sulphate and sodic chloride. Zincic chloride is a whitish-gray translucent substance, soft like wax, and of 2.7 spec. grav. It melts easily and distills at a red heat; it is deliquescent, dissolves easily in water and alcohol; has a burning taste, and is poisonous. It is used in various chemical manufactures. Wood, impregnated with a crude solution of zincic chloride known under the name of "Sir William Burnett's Fluid," is effectually preserved from decay, this process being called Burnettizing. *Zincic sulphate*, $ZnSO_4 + 7H_2O$ (White Vitriol), may be prepared either by roasting zincic sulphide, or by the action of sulphuric acid on metallic zinc. It strongly resembles magnesic sulphate, and is used in medicine, and in certain operations of calico-printing.

CADMIUM.—Symbol, Cd. Atomic Weight, 112; Quantivalence, II.; Molecular Weight, 112; Molecular Volume, 2; Specific Gravity, 8.6.

**449. Cadmium.**—This metal does not occur native, but may be obtained from ores of zinc, and from some of the secondary products of zinc-manufacture. It is a bluish-white, strongly lustrous metal, tarnishing in the air. It is soft, flexible, malleable, and ductile, melts at 315° C., is volatile, and crystallizes from the fused state, in regular octahedrons. In the air at higher temperatures it burns, cadmic oxide (CdO) being formed.

# CHAPTER XXI.

## IRON, MANGANESE, NICKEL, AND COBALT.

### § 1. *Iron and its Compounds.*

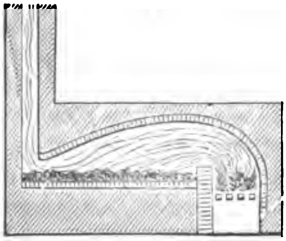
IRON.—Symbol, Fe. (Ferrum). Atomic Weight, 56; Quantivalence, II., IV., and VI.; Specific Gravity, 7.8.

**450. History and Occurrence.**—Were we to seek for that circumstance which might best illustrate the peculiarities of ancient and modern civilization, we should perhaps find it in the history of this metal. The ancients, imbued with a martial spirit and passion for conquest, made iron the symbol of war, and gave it the emblem of Mars. And if it were required also to symbolize the pacific tendencies of modern society, its triumphs of industry and victories of mind over matter, its artistic achievements and scientific discoveries, we should naturally employ the same metal, *iron.* As gold and jewels have long been the type of barbaric and empty pomp, so iron may now be well regarded as the emblem of beneficent and intelligent industry.

Native iron of meteoric origin has frequently been found, and instances of its occurrence on the earth have been reported, but usually in these cases the iron is combined with nickel. We are, however, acquainted with numerous ores of iron, among which are magnetite, red hematite, and specular iron, brown iron-stones, spathic iron, and clay iron-stone.

**451. Preparation.**—Metallic iron or wrought-iron has been obtained from iron-ores, and to some extent this is still its source, but by far the largest portion brought into the market is derived from the decomposition of cast-iron, which is essentially a ferric carbide, but also contains varying quantities of other substances. The operation is usually conducted in reverberatory furnaces. In this process, the cast-iron is melted on a flat hearth by causing the flame to impinge upon it from above on its way through the furnace, as shown in Fig. 171. A workman, with a long, oar-shaped implement of iron, stirs (*puddles*) the melted mass until the carbon and other impurities of a like nature are burned away or converted into a slag, and the metal becomes thick and pasty. This is called *puddling*. The puddler then rolls up from the mass a ball of about 75 lbs. weight, which he transfers to the tilting or trip hammer, where it is beaten by heavy blows into a crude bar. By this operation the liquid slag, consisting chiefly of ferrous silicate, is squeezed out, as water is expelled from a compressed sponge. The metal, still hot, is then passed between grooved cylinders, where it is rolled out into *bar-iron*. The quality of metal is greatly improved when these bars are broken up, bound together, reheated to the welding-point, and again passed through the rolling-mill. This latter operation is often repeated several times, and is known as *piling* or *fagoting*.

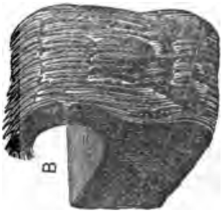
FIG. 171.



Puddling-Furnace.

**452. Properties.**—Pure iron is of a silver-white color, while ordinary wrought-iron is grayish-white, and when polished has a perfect lustre. In the absence of impurities, iron is so malleable that books have been made of it with leaves as thin as paper, and so ductile that it may be drawn out into wires as thin as a hair. Its most useful quality, however, is its superior tenacity, or power of resisting strain; no other metal being equal to it in this respect. Hence the value of iron in the manufacture of cannons and mortars, where the immense expansive force of gunpowder is to be resisted, and in the making of wire cables for suspension bridges. So great is its tenacity that an iron wire 0.075 of an inch in diameter is capable of supporting a weight of 449 pounds.

FIG. 172.



Texture of Wrought-Iron.

Wrought-iron has a fibrous texture, and rough, hackly fracture, Fig. 172. It is said that the effect of constant jarring is to cause it to lose this tough, fibrous character, and to become crystalline. It usually contains a small quantity of carbon, which hardens the iron without affecting its other properties to any great extent; but if the amount exceeds $\frac{1}{2}$ per cent., it renders the iron *cold-short*, that is, brittle and liable to snap asunder when cold. The presence of sulphur, even in so small a proportion as $\frac{1}{10,000}$, unfits the iron for being worked at a red heat, as it is liable to split when hammered; it is then said to be *hot-short.*

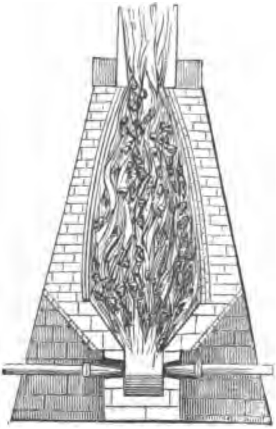
**453.** When wrought-iron is heated to whiteness, it becomes soft, pasty, and adhesive, and two pieces in this condition may be incorporated, or hammered into one. This is called *welding.* During the heating a film of triferric tetroxide is formed upon the surface of the metal, which would obstruct the ready cohesion of the separate masses. To prevent this, the smith sprinkles a little sand upon the hot iron, which gives rise to the formation of a fusible silicate, easily forced out by pressure, leaving clean surfaces that unite without difficulty. This important quality is possessed only by iron, platinum, and sodium. All the other metals pass suddenly from the solid to the liquid state, at their respective melting-points. In its ordinary condition iron oxidizes rapidly in the air, and dissolves in nitric acid. But under several circumstances it assumes different, and peculiar chemical relations. If momentarily immersed in a strong mixture of nitric and sulphuric acids it retains its metallic lustre, but has lost the power of either being oxidized in the air or of dissolving in nitric acid; it has become *passive*, or assumed an allotropic form.

**454. Uses.**—Iron in some of its innumerable forms ministers to the benefit of all. The implements of the miner, the farmer, the carpenter; the mason, the smith, the shipwright, are made *of* iron and *with* iron. Roads of iron, traveled by iron steeds, which drag whole townships after them and outstrip the birds, have become our commonest highways. Ponderous iron ships are afloat upon the ocean, with massive iron engines to propel them; iron anchors to stay them in storms; iron needles to guide them, and springs of iron in chronometers by which they measure the time. Ink, pens, and printing-presses, by which knowledge is scattered over the world, are alike made from iron.

**455. Ferric Carbides** (*Cast-Iron*).—As already stated, most of the wrought iron of commerce is obtained from the ore indirectly, the latter being first decomposed in such a manner as to yield certain ferric carbides, etc., known as cast or pig-iron.

The operation is conducted in tall chimney-like structures, termed blast-furnaces. They are constructed of stone, and lined with the most refractory fire-brick, having the form seen in Fig. 173. The top or mouth of the furnace serves for charging it, and for the escape of smoke; it is both door and chimney. The tubes or *tuyere pipes* at the bottom serve to supply the air, which is forced in by means of immense blowing cylinders driven by water or steam power. The amount of air thus forced through some large furnaces exceeds 12,000

FIG. 173.

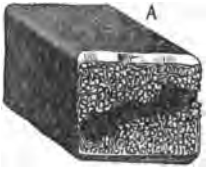


Smelting-Furnace.

cubic feet per minute. Formerly the air was used at the ordinary temperature (*cold blast*), but within a few decades an immense improvement has been effected by heating the air before it enters the furnace (*hot blast*).

**456.** In some cases the materials are drawn up an inclined plane to the mouth of the shaft by the same engine that impels the blast mechanism. The furnace is supplied with ore, coal, and limestone, broken into small fragments. When the heat is sufficiently intense the carbon of the fuel deoxidizes the iron, and the limestone being decomposed into carbonic dioxide gas, which escapes, and " burnt lime," which in its turn acts upon the ore, unites with the sand, clay, silica, and other impurities, to form a *slag* or *scoria*, a crude semi-vitreous, easily-fusible product. The melted cast-iron, falling to the bottom of the furnace, accumulates and is drawn off by taking out a *tap* or *plug*. It is allowed to run into a bed of sand, containing straight channels and furrows running at right angles. The former are called by the workmen the *sow*, and the latter the *pigs;* hence the term *pig-iron*. As the contents of the furnace are removed from below, crude-ore, limestone, and fuel are constantly supplied from above, and the operation goes on day and night uninterruptedly for a course of years, or until the fabric demands repair.

FIG. 174.



Texture of Cast-Iron.

**457.** Cast-iron has a granular texture (Fig. 174), and is so brittle that it cannot be forged, but may be remelted and cast into moulds. It expands when first poured into the mould, so as to copy it perfectly, but subsequently contracts. The expansion is caused by the particles assuming a crystalline arrangement while consolidating; the contraction by the cooling of the metallic mass when solidified. There are several varieties of cast-iron. The so-called "Spiegeleisen" (mirror-iron) of Germany is a nearly pure tetraferric carbide, $Fe_4C$. Other varieties appear to be mixtures of this compound with artificial plumbago (a variety of carbon), or with true metallic iron.

**458. Steel.**—This is a compound of the metal with about one and a half per cent. of carbon. It is produced in different ways. One variety is made by imbedding bars of the best wrought-iron in powdered charcoal, in boxes or sand-furnaces, which exclude the air, and heating it intensely for a week or ten days. The chemical changes are obscure; probably carbonic oxide penetrates the heated metal, is decomposed, surrenders part of its carbon and escapes as carbonic dioxide. The steel when withdrawn has a peculiar rough, blistered appearance, and is therefore known as *blistered steel.* This method of making steel is called the process of *cementation.* When this quality of steel is melted and cast into ingots, it constitutes cast-steel.

A great improvement in the manufacture of steel has been introduced, called from its inventor the Bessemer process. By means of this, steel is produced directly from the cast-iron, without previous casting into pigs. The melted cast-iron is run from the shaft-furnace into egg-shaped vessels made of boiler-plate, lined with fire-clay, which are termed "converters." An intense blast of compressed air is forced into the molten mass, and ten to twenty-five minutes of this operation suffice to decarbonize the cast-iron so as to convert it into steel, or wrought-iron, as may be desired.

**459.** In its properties steel combines the fusibility of cast-iron with the malleability of bar-iron. Its value for cutting instruments, springs, etc., depends upon its quality of being *tempered.* When heated to redness and suddenly quenched in cold water, it becomes so hard as to scratch glass. If again heated and cooled slowly, it becomes as soft as ordinary iron, and between these two conditions any required degree of hardness can be obtained. As the metal declines in temperature, the thin film of oxide upon its surface constantly changes its color. The workmen are guided by these tints. Thus a straw-color indicates the degree of hardness for razors; a deep blue for sword-blades, saws, and watch-springs. Steel receives a higher polish than iron, and has less tendency to rust. Nitric acid placed upon steel corrodes it, and leaves the carbon as a dark-gray stain; hence it is often used for writing and ornamental shading upon this metal.

**460. Ferrous Oxide,** $\overset{II}{Fe}O$.—This compound is not found native, but is obtained when ferrous oxalate is heated in a close vessel, as a black powder, which in the air ignites spontaneously, burning to *ferric oxide*, $\overset{VI}{Fe}_2O_3$ (diferric trioxide), which is of very wide distribution as the minerals red hematite and specular iron, from which a large proportion of the iron of trade is derived. Red hematite is massive, earthy, or fibrous, and brick-red in color. Specular iron is extensively employed under the names of colcothar and jewelers' rouge, as a pigment, and for polishing jewelry, glass, and metallic objects.

**461. Triferric Tetroxide,** $Fe_3O_4$, *Magnetic Oxide.*—This substance occurs native as the mineral magnetite, the most valuable of the ores from which iron is produced. This appears as a black, crystalline powder, in Nature it forms large masses, and is frequently found in distinct octahedral crystals of considerable size. The triferric tetroxide is strongly magnetic, and the black oxide which forms on iron when heated in aqueous vapor consists of this compound, which is also produced by the combustion of iron in oxygen gas.

**462. Ferric Disulphide,** $\overset{VI}{Fe}S_2$.—This compound occurs native in two isomeric modifications, one, the mineral marcasite, the other, iron pyrites. Both forms are widely distributed. Iron pyrites crystallizes in cubes or other forms of the monometric system, of a golden-yellow color and strong metallic lustre. Heated in the air, iron pyrites burns with evolution of sulphurous oxide, and it is much used in the manufacture of sulphuric acid. Sulphur and copperas are also obtained from it, but it is never worked for iron. Marcasite is a mineral possessed of a white color and metallic lustre, which in moist air decomposes rapidly, with formation of ferrous sulphate ($FeSo_4+7H_2O$) and evolution of heat. It occurs in coal-beds, and sometimes causes their spontaneous ignition.

**463. Ferrous Sulphate,** $FeSo_4+7H_2O$, *Green Vitriol, Copperas.*—This salt is largely manufactured from iron pyrites. It is used in dyeing, for making ink and Prussian blue, and in medicine. It often exists in soils to a pernicious extent, but is decomposed by lime, gypsum being formed. *Ferrous Carbonate,* $FeCO_3$. This is a very abundant mineral known as spathic iron. It is grayish-white, opaque, and crystallizes in rhombohedrons. When found in large masses it constitutes one of the most valuable iron-ores. Steel has been made directly from it, hence it is known as steel-ore.

## § 2. *Manganese, Nickel, and Cobalt.*

MANGANESE.—Symbol, Mn. Atomic Weight, 55; Quantivalence, II., IV., and VI.; Specific Gravity, 8.

**464.**—This metal never occurs in Nature, but can be obtained by making manganic oxide into a paste with oil and lamp-black and heating this mixture to whiteness in a covered crucible. It is a hard, brittle metal of a grayish-white color, and rapidly oxidizes when exposed to the air. It is best preserved in naphtha. *Manganic Dioxide,* $MnO_2$, occurs in Nature as the mineral *pyrolusite.* It is an iron-black or steel-gray, brittle substance, crystallizing in forms of the trimetric system. It is mined extensively, being employed in the manufacture of chlorine and bleaching-powders, as a source of oxygen, and for discharging the brown and green tints of glass.

**465. Nickel and Cobalt.**—These two metals are closely related by their properties. Their atoms have identical weights, and their reactions are so similar that there is difficulty in separating one from the other. They occur associated together, and are found alloyed with the iron of meteoric origin.

They may be obtained by the decomposition of ores, chiefly nickelic and cobaltic arsenides, sulphides, and sulph-arsenides. They are both magnetic, and resemble iron in many of their properties. Nickel is a silver-white, ductile and malleable metal, of about 8.4 spec. grav., not much more fusible than iron. It is used principally in the manufacture of german silver, of coinage, and other similar alloys. Cobalt is a reddish or grayish-white metal, of about 8.9 spec. grav.; hard and somewhat malleable at a red heat. It has not been applied to any useful purpose. *Cobaltous Chloride*, $CoCl_2+6H_2O$, may be obtained in ruby-red octahedral crystals from solutions of cobaltous oxide or carbonate, in hydric chloride. The dilute solution of these is used as a sympathetic ink, the characters written with it being so pale as to be invisible till warmed, when they appear blue, owing to the formation of the anhydrous chloride ($CoCl_2$). On cooling, they absorb moisture and again disappear.

## CHAPTER XXII.

### CHROMIUM, ALUMINIUM, AND THE PLATINUM GROUP.

### § 1. *Chromium and its Compounds.*

CHROMIUM.—Symbol, Cr. Atomic Weight, 52.5; Quantivalence, II., IV., and VI.; Specific Gravity, 6.8.

**466. Occurrence.**—This metal may be prepared by exposing chromic compounds to intense heat in a current of hydrogen gas or by fusing its oxide with charcoal in a charcoal-lined crucible. When the oxide is reduced by carbon the metal obtained is of steel-gray color, exceedingly hard, and not easily fused. Many of the compounds have a brilliant color and are used as paints. It gives color to the emerald.

**467. Dichromic Trioxide,** $\overset{VI}{Cr}_2O_3$, *Chromic Oxide.*—This compound may be obtained, by strongly heating a chromic hydrate, as a bright-green powder, or in the form of greenish-black rhombohedral crystals of metallic lustre, 5.2 spec. grav., and great hardness. It is used in coloring glass and porcelain, and also in ordinary painting under the name of chrome-green. *Chromic Trioxide,* $\overset{VI}{Cr}O_3$, is obtained in splendid crimson needle-shaped crystals often an inch in length, easily soluble in water, melting at 190° C., and decomposing at 250° C. It is a powerful oxidizing agent.

## § 2. *Aluminium and its Compounds.*

ALUMINIUM.—Symbol, Al. Atomic Weight, 27.5; Quantivalence $(Al_2)^{VI}$; Specific Gravity, 2.5.

**468. History.**—This important metal was discovered by the German chemist Wöhler in 1827. It is not found native, but may be obtained by decomposing either the chloride or the fluoride with metallic sodium. It is one of the most abundant elements, being the metallic base of alumina, which forms the argillaceous rocks, beds of clay, and a large proportion of granite. It is a shining, white metal, of a shade between silver and platinum, harder than zinc and of remarkable strength and stiffness. It resists, like silver, the oxidizing influence of moist air, melts at a still lower temperature than that metal, and, pound for pound, occupies four times its space. It is the most sonorous of metals, giving forth a clear musical sound when struck. It is malleable and ductile like iron, exceeds it in tenacity, and combines with carbon, forming a cast metal, which is not malleable.

It conducts electricity nearly as well as silver, and unlike silver is not tarnished by hydric sulphide. Nitric and sulphuric acids, when cold, do not act upon this metal. It dissolves in hydric chloride, forming aluminic chloride, and in potassic or sodic hydrate solutions with production of corresponding aluminates. At present, aluminium is principally employed in the manufacture of aluminium bronze, small weights, and optical instruments.

**469. Aluminic Oxide,** $Al_2O_3$, *Alumina.*—This compound is found native. Crystallized and colored by chromic oxide it forms the ruby and sapphire, which rank next to the diamond in hardness and value. In a pure massive form it is known as *corundum*, and this when ground constitutes *emery.* It may be artificially prepared by heating aluminic hydrate. It is a white powder, insoluble in water, inodorous and tasteless.

**470. Aluminic Silicates.**—These bodies form the chief constituents of clays, which result from the decomposition of feldspathic and silicious rocks, and are the basis of all kinds of pottery. Their adaptation for this purpose depends upon their plasticity when mixed with water, the readiness with which they may be moulded, and also upon their capability of solidifying when exposed to a high heat. After burning, the ware, though hard, is porous, and absorbs water with avidity, even allowing it to filter through. To prevent this, the ware is covered with a glassy coating, or glazed.

**471. Porcelain** consists of a mixture of decomposed feldspar (called *kaolin*), silica, and a small proportion of lime, the ingredients being carefully selected, and thoroughly ground and incorporated. When moulded into the proper form, the articles are dried and subjected to a high heat in a furnace, in which state the ware is called *biscuit.* They are then glazed by dipping them into a solution of powdered quartz and feldspar, which, when heated, fuses into the ware, giving it a vitreous coating which adds to its compactness and strength. The partial fusion of the materials gives porcelain the beautiful semi-transparency which distinguishes it from earthen-ware. In coloring porcelain, the patterns are printed on paper which is applied to the biscuit while the color is still moist. When the color is absorbed, the porcelain is subjected to another baking, which fixes the tint. In the finer kinds of porcelain the colors are mixed with a fusible glaze, and applied with a hair pencil. Common red pottery ware owes its color to ferric oxide ($Fe_2O_3$), and is glazed with a preparation of clay and plumbic oxide. Vessels thus coated are objectionable for domestic use, as the lead-glaze is sometimes dissolved by acids, producing poisonous effects. Bricks are unglazed. *Stone-ware* is a coarse kind of porcelain glazed with salt. Fire-bricks, muffles, and Hessian crucibles, are made of a pure, infusible clay, containing a large amount of silica. The beautiful blue pigment ultramarine is one of the aluminic silicates supposed to be colored by a sodic sulpho ferrate. A variety of clay known as fuller's-earth is also used to remove grease from woolen cloths.

**472. Potassio-Aluminic Sulphate.** $\overset{\mathrm{I}}{K}\overset{\mathrm{IV}}{Al}S_2O_8+12H_2O$, *Alum.*—Small quantities of this important salt are found native, but for commercial purposes it is prepared artificially by several different methods. In this country it is formed by treating alumina or clay with sulphuric acid, and, after the lapse of a few months, adding potassic sulphate or carbonate. The whole is then leached, and the alum separated from the solution by crystallization. Alum is used largely for purifying and preserving skins, for mordants in dyeing and calico-printing, for glazing paper, for hardening and whitening tallow, clarifying liquors, and in medicine as an astringent and caustic. Wood impregnated with it is almost incombustible. Alum has a sweetish, styptic taste, and is soluble in 18 parts of cold water, or in its own weight of boiling water, the solution having an acid reaction. When heated, alum swells up into a light, puffy condition, at the same time giving off its water of crystallization, and leaving a white, anhydrous, infusible mass known as *burnt alum.*

## § 3. *The Platinum Group.*

PLATINUM.—Symbol, Pt. Atomic Weight, 197; Quantivalence, II. and IV.; Specific Gravity, 21.5.

**473.** This rare metal is always found native, and usually associated with palladium, rhodium, and iridium. It also occurs alloyed with gold, copper, iron, and lead. Its chief sources are the mines of Mexico, Brazil, and the Ural Mountains. Platinum is of a grayish-white color, and closely resembles silver in appearance. It is one of the heaviest of metals, and when pure it scarcely yields in malleability to gold and silver; is very ductile, and takes a good polish. But the qualities which render it so useful, and in some cases indispensable to the chemist, are its extreme difficulty of fusion (being unaffected by any furnace heat), and the perfect manner with which it resists the action of almost all acids. It does not oxidize in the air at any temperature, and is not acted upon by simple acids. It is slowly dissolved by aqua regia. We have already alluded (259) to the power possessed by *spongy platinum* of condensing gases and causing the union of oxygen and hydrogen. *Platinum-black* is a preparation of the metal in a still more minute state of subdivision, and has the property of effecting chemical changes more energetically than platinum sponge. It may be produced by electrolyzing a dilute solution of the metal.

**474. Platinic Tetrachloride,** $PtCl_4$, is obtained by dissolving platinum in aqua regia and evaporating the solution over the water-bath. It is a brownish-red substance, soluble in water and alcohol, forming a reddish-yellow solution.

It is a valuable reagent for potassic, rubidic, and cæsic compounds.

***Rhodium, Ruthenium, Palladium, Iridium, and Osmium,*** **are rare and generally found associated with platinum, which they resemble both in appearance and properties.**

## CHAPTER XXIII.

### TIN, SILICON.

### § 1. *Tin and its Compounds.*

**TIN.—Symbol, Sn. (Stannum) Atomic Weight, 118; Quantivalence, II. and IV.; Molecular Weight 236 (?); Specific Gravity, 7.29.**

**475. History and Occurrence.**—Tin is a brilliant, silver-white metal, which has been found native only in small quantities, and in few localities. It is obtained on a large scale by the decomposition in furnaces of various ores, of which the mineral cassiterite is the most important. It is softer than gold, slightly ductile and very malleable, and may be beaten into leaves one-fortieth of a millimetre thick. It melts at 442° F. The peculiar crackling sound given by tin when bent is due to a disturbance of its crystalline structure. It tarnishes but slightly on exposure to the air or moisture, and is therefore very valuable for domestic utensils. This property also renders it useful for coating other metals to prevent them from oxidizing. Sheet-iron coated with tin, with which it forms an alloy, constitutes common tin-ware.

**476. Stannic Dioxide,** $SnO_2$, *Oxide of Tin.*—This compound exists in several modifications. It is found native, as the mineral cassiterite, in broad square prismatic crystals. More or less rounded by attrition, these crystals are met with in the alluvial deposits of rivers forming "stream-tin," from which metallic tin is obtained. Another modification may be obtained in the form of colorless prisms of the trimetric system, which are very hard and brilliant. Stannic dioxide is much used in the manufacture of enamels and opaque glasses. *Britannia metal* is a white alloy much resembling German-silver in appearance. It consists chiefly of tin and antimony in the proportion of 9 parts of the former to 1 part of the latter.

*Titanium*, *Zirconium*, *Thorium*, are but little known and comparatively unimportant. They are allied to tin by many of their properties.

## § 2. *Silicon and its Compounds.*

SILICON.—Symbol, Si. Atomic Weight, 28; Quantivalence, IV.; Molecular Weight 56 (?); Molecular Volume, 2; Specific Gravity, 2.49.

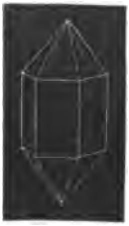
**477. Silicon.**—This element is never found native, but may be prepared by decomposing silicic fluoride or chloride with sodium or aluminium. It has three allotropic states: first, amorphous silicon—a brown powder; second, a crystalline hexagonal variety resembling graphite; and a third, octahedral form which is exceedingly hard. It is of no importance except to the scientific chemist.

**478. Silicic Dioxide,** $SiO_2$, *Silica.*—This compound is one of the most important and widely-distributed of substances; forming the bulk of the minerals, quartz, flint, agate, chalcedony, opal, etc., and of most sandstones, and sandy soils. It is also an essential and sometimes predominating ingredient in granite, and many other rocks. It exists in two modifications: one crystalline, the other amorphous. In both of these conditions it is almost infusible. By the intense heat of the oxy-hydrogen blow-pipe it is reduced to a transparent glass, and may be spun out into threads.

Both modifications of silica are insoluble in water, and in all acids, except the fluohydric, but it is dissolved by solutions of alkaline silicates. Hence, all natural waters which contain alkaline silicates may also contain a little silica. When water containing even small quantities of alkaline carbonates acts upon silica under pressure and at temperatures from 300° to 400° C., it is capable of dissolving a large quantity of it, which is again deposited when the pressure and heat are removed. This is the cause of the siliceous deposits formed by certain hot springs, as the geysers of Iceland. If wood be present in such waters, as it decays, the particles of silica are deposited in place of those that escape, and thus a copy of the wood in stone, or a *petrifaction*, is produced.

**479. Crystalline Modification.**—This is found in Nature as quartz, amethyst, etc., forming rhombohedra or hexagonal crystals terminated by six-sided summits (Fig. 175), which are sometimes of enormous size. It is very hard, colorless when pure, and often quite transparent. The amorphous modification of silicic dioxide is a pure white powder. This compound, with varying quantities of water held hygroscopically, constitutes the *opal.*

FIG. 175.



Quartz-Crystal.

**480. Silicic Fluoride,** $SiF_4$. — This is a colorless gas produced when hydric fluoride acts upon silica. When passed into water the gas is decomposed, with formation of hydric silicate, and a peculiar compound known as hydric fluo-silicate, $H_2SiF_6$.

*Silicic Acids.*—If to a solution of sodic or potassic silicate hydric chloride be added, silicic acid separates as a transparent jelly, which is nearly insoluble in water or acids. By reversing the operation, that is, by pouring the sodic, etc., silicate solution into the hydric chloride, no precipitate results, but by subjecting this mixture to dialysis a clear aqueous solution of silicic acid may be obtained. The exact composition of these hydric silicates is not known. This gelatinous state may be continued by keeping it moist, but as soon as it is deprived of water it falls to a gritty powder.

**481. Glass.**—When mixtures of pure quartz-sand with potash, or soda, and various metallic oxides, are strongly heated, they fuse to a liquid, which on being gradually cooled before solidifying passes through a thick, viscous, semi-fluid condition. While in this state they may be moulded into any desired shape, retaining their form and transparency when cold. Thus we have a compound easily moulded at a certain stage of fusion, uncrystalline when cold, but transparent, hard, strong, insoluble, and durable—that is, common glass. The *materials* for the manufacture of glass are, first, pulverized quartz or sand—for the manufacture of the finest varieties of glass a pure white sand free from ferric oxide is employed—second, the basic constituents, potash, soda, lime, magnesia, and lead-oxides more or less pure, according to the quality of the glass required. Various metallic oxides are also employed as coloring agents. Thus cupric oxide gives a green color, gold oxide a ruby, uranic oxide a yellow, cobaltic oxide a deep-blue, manganic oxide a purple, and a mixture of cobaltic and manganic oxides a black glass. Enamel watch-dials and semi-opaque transparencies are glass rendered milk-white by stannic oxide or bone earth.

**482. Varieties of Glass.**—The silicates of lime, magnesia, iron, soda, and potash, in their impure form, produce the coarser kinds of glass of which green bottles are made. The silicates of soda and lime give the common window-glass and French plate. Lime hardens glass, and adds to its lustre; soda tends to give it a greenish tinge. *Bohemian glass*, the most beautiful variety, hard and highly infusible, is a silicate of potash and lime. *Crystal glass*, or *flint glass*, so called because pulverized flints were formerly used in making it, is a potassio-plumbic silicate. The red plumbic oxide renders it very soft, so as to be easily scratched, but greatly increases its transparency, brilliancy, and refractive power. Sometimes the proportion of oxide of lead used rises as high as fifty-three per cent. Glass of this composition forms what is called *paste*, and, when suitably cut, is used to imitate the diamond. By the addition of a trace of ferric oxide the yellow of the topaz is imitated, and by cobaltic oxide the brilliant blue of the sapphire is produced.

# CHAPTER XXIV.

## *Carbon and its Compounds.*

CARBON.—Symbol, C. Atomic Weight, 12; Quantivalence, II. and IV.; Molecular Weight 24 (?); Molecular Volume, 2; Specific Gravity (Diamond), 3.5.

**483. History and Properties.**—*Carbon*, from the Latin *carbo*, coal, is the name applied to the solid with which we are familiar in the various forms of charcoal, mineral coal, lamp-black, etc. It is met with in three well-marked allotropic forms—the diamond, graphite, and charcoal. The purest form of carbon is the *diamond*—a very extraordinary kind of matter. It crystallizes in regular octahedrons or other forms of the monometric system, the faces being frequently convex (Figs. 176, 177, and 178), and is the hardest body known. Diamonds are found in the earth in various places, usually in the form of rounded pebbles covered with a brownish crust. Of their

FIG. 176.

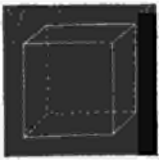


FIG. 177.

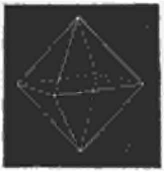
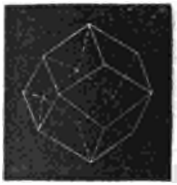


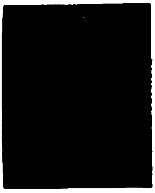
FIG. 178.



mode of production nothing whatever is known. The finest specimens are perfectly colorless and limpid, but they are also of various colors. The diamond has a very high refractive and dispersive power by which it flashes the most varied and vivid colors of light. It is a non-conductor of electricity, and resists the action of all known chemical substances. The diamond remains unchanged at a very high degree of heat; but, if made red-rot and carried into pure oxygen, it burns with a steady glow, like a little star, the product being carbonic dioxide. From its high refractive power, resembling in this respect some organic substances, Newton predicted that it would prove not only combustible, but of *organic origin.* This view seems to be supported by the fact that the crystal on being burned leaves a trace of ash in the form of a cellular net-work. In the flame of the voltaic arc, the diamond becomes white-hot, swells, and is converted into a black, coke-like mass. The diamond is the most brilliant and precious of gems. Being a powerful refractor of light, it has been sometimes employed for the lenses of microscopes, but it is chiefly used for cutting glass and drilling apertures through other gems.

**484. Graphite,** or **Plumbago,** is another allotropic form of carbon. It is found in rocks, sometimes in considerable masses, and crystallizes in six-sided plates of a metallic lustre, resembling lead, Fig. 179; hence it is called *black-lead.* Its spec. grav. is about 2.1. Like the diamond, it resists the action of intense heat, and is useful to the chemist in making crucibles. It is friable, has an unctuous feel, and is used instead of oil to relieve the friction of machinery. It is unaffected by the weather, and hence forms a valuable coating to protect iron-work from rust; and, as it resists heat, it is fitted for stove-polish. It is, however, often adulterated largely

FIG. 179.



with lamp-black, which may be detected by heating the suspected sample to redness, when the lamp-black burns away. Its most important use is in the manufacture of pencils. The powder, subjected to enormous pressure, coheres in masses, and is then sawed into thin slices, and again into small bars, which are placed in grooved cedar-sticks for use. Though apparently so soft, the particles of graphite are extremely hard, and soon wear out the steel saws with which the mass is cut.

Graphite, unlike diamond, may be artificially produced. When cast-iron, which has been melted in contact with an excess of carbon, is allowed to cool slowly, the carbon crystallizes out in the form of graphite. In the manufacture of coal-gas, a layer of pure, dense carbon, having a metallic lustre, is deposited upon the hottest parts of the retort. It is called *gas-carbon*, and seems to be a variety of graphite, if, indeed, it be not itself an allotropic form of carbon.

**485. Charcoal**, the third well-settled allotropic variety of carbon, is obtained when any organic substance, as wood, bones, or sugar, is strongly heated or burned with a partial exclusion of air. It is ordinarily prepared by covering large heaps of wood with ashes or turf, and burning them with a restricted supply of air, so as to prevent complete combustion, and only char the wood. The finer kinds of charcoal, such as are used for making gunpowder, are produced by distilling the wood in close iron retorts. Charcoal is a black, brittle, inodorous, tasteless solid; a good conductor of electricity, but a bad conductor of heat, and perfectly insoluble in all liquids. It is oxidized by strong hydric nitrate, but resists the action of air and moisture, and is, therefore, very unchangeable. The timbers, and grains of wheat and rye, converted into charcoal eighteen hundred years ago, at Herculaneum, remain as entire as if they had been charred but yesterday. Wooden posts are rendered more durable by charring their ends before placing them in the ground. The interiors of tubs and casks are often charred for the same reason.

**486. Uses.**—The chief use of charcoal is as a fuel. When pure, it burns without flame, although it usually contains water which, during the combustion, is partially decomposed and hydric carbide is formed which burns with a slight flame. A cubic foot of charcoal from soft wood weighs from 8 to 9 lbs.; from hard wood, from 12 to 13 lbs.; hence, hard-wood coal is best adapted to produce a high heat in a small space. At high temperatures, charcoal has a very powerful affinity for oxygen; therefore, it is of great value in reducing metals from their oxides, in the smelting-furnace.

Having the structure of the wood from which it was derived, charcoal is very porous, and possesses in a remarkable degree the power of absorbing gases, and condensing them within its pores. It will absorb 90 times its bulk of ammonia; 35 times its bulk of carbonic dioxide; and 9 times its bulk of oxygen. Freshly-burned charcoal imbibes watery vapor from the air very greedily, and by a week's exposure increases in weight from 10 to 20 per cent. Charcoal, having the finest pores, possesses this power of absorption in the greatest degree; the spongy sort least. "A cubic inch of charcoal," says Liebig, "must have, at the least computation, a surface of 100 square feet." Charcoal absorbs noxious gases and offensive odors; and, when crushed, foul water filtered through it, and tainted meat packed in it, are restored to sweetness. The charcoal from bones (bone-black) is superior to wood-charcoal for purifying purposes. It is extensively used in sugar refineries to decolorize syrups. Vinegars, wines, etc., are bleached in the same way.

Charcoal is a powerful deodorizer and disinfectant, but it is not an antiseptic, or preventer of change, as has been supposed. In fact, it is an *accelerator* of decomposition. It was formerly thought that charcoal acted by simply sponging up the deleterious gases, and retaining them in its pores; but it has been lately shown that, by means of its condensing power, it is a powerful agent of destructive change. The condensed oxygen seizes upon the other gases present, and, oxidizing them, forms new products. It thus changes ammonia to hydric nitrate, and hydric sulphide to hydric sulphate. The body of a dead animal packed in charcoal emits no odor, but, instead of being preserved, its decomposition is much hastened. This property has been made medically available in the form of charcoal-poultice, to aid in the removal of sloughing and gangrenous flesh in malignant wounds and sores. *Lamp-black* is an impure variety of charcoal. It is the soot deposited from the burning of pitchy and tarry combustibles. The smoke is conducted through long horizontal flues terminating in chambers hung with sacking, upon which the lamp-black is deposited. It is used for making printers' ink and black paint.

**487. Carbonic Monoxide**, $CO$, *Carbonic Oxide*, is a colorless, almost inodorous gas, which burns with a pale-blue flame. It is produced by burning carbon with an imperfect supply of air, and its formation may be observed in an open coal-fire. At the lower part of the grate, where the air is abundant, carbonic dioxide is formed. As it ascends into the hot mass above, it loses half of its oxygen, becoming carbonic monoxide. The liberated oxygen, combining with the carbon of the fuel, also produces an equal quantity of the gas. As the carbonic monoxide thus formed rises to the surface of the fire, it burns to carbonic dioxide, with a lambent, blue flame. This gas may be obtained pure and in great quantities by heating 1 part of potassic ferrocyanide with 10 of hydric sulphate in a capacious retort. Carbonic monoxide, when respired, acts as a violent poison. Even when mixed with a very large quantity of air its inhalation produces giddiness and headache, and has in many instances proved fatal.

**488. Carbonic Dioxide, $CO_2$,** *Carbonic Acid.* — This compound was discovered by Van Helmont about the beginning of the seventeenth century. It is a normal constituent of the atmosphere, to the average amount of 4 volumes in 10,000. Wherever carbon in any of its modifications, or any carbonic compounds, burn, with free access of air, carbonic dioxide is produced. The combustion of a bushel of charcoal produces 2,500 gallons of the gas. It is produced by fermentation, and the slow decomposition of organic bodies, and also by the respiration of animals. Each adult man exhales about 140 gallons per day. It is also produced by chemical changes which take place in the interior of the earth, and it comes up with the waters which rise to the surface. In volcanic regions it is occasionally met with, unmixed with other gases. Rising to the surface, often more rapidly than it is diffused into the air, it accumulates in invisible pools and ponds. Through the celebrated *Grotto del Cane*, in Italy, a man may walk unharmed, but a dog with its nostrils near the earth is suffocated on entering. The poison valley of Java is a lake of carbonic dioxide filled with the bleached bones of dead animals.

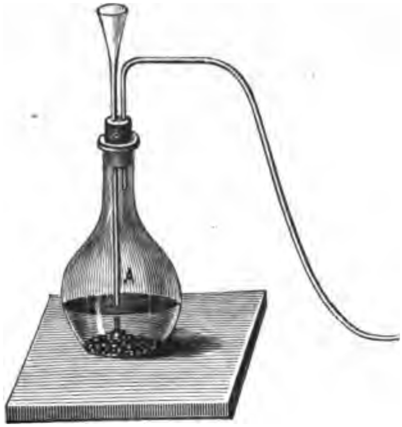
**489. Preparation.**—Carbonic dioxide is most conveniently obtained by the action of an acid upon small fragments of marble, limestone, or chalk. Any strong acid will answer the purpose, but hydric chloride is the best. The powdered mineral is placed in a jar and covered with water. A little dilute acid is then poured down through the tube, Fig. 180. Effervescence immediately takes place, and the gas escapes through the bent tube. It may be collected over water in the pneumatic trough, or, as it is heavier than the air, it will quickly displace it in an open vessel. The change is thus shown:

$$CaCO_3 + 2HCl = CaCl_2 + H_2O + CO_2.$$

A cubic inch of marble will yield four gallons of the gas.

**490. Properties.**—Carbonic dioxide is, at ordinary temperatures and pressures, a colorless, inodorous gas, of 1.52 specific gravity. It does not support combustion. To prove this, and to show also that it is heavier than air, we have but to place a lighted taper in a jar, and pour in carbonic dioxide from another vessel, Fig. 181; the invisible current promptly puts out the light.

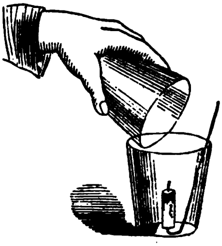
FIG. 180.



Jar for generating Carbonic Dioxide.

When respired, carbonic dioxide is fatal to life. If pure, it produces spasm of the glottis, closes the air-passages, and thus kills suddenly by suffocation; but, though it has been held that carbonic dioxide exerts a poisonous action, it is more probable that these effects are merely due to deprivation of oxygen. This gas often accumulates at the bottom of wells, and in cellars, stifling those who may unwarily descend. To test its presence in such cases, it is common to lower a lighted candle into the suspected place, and, if it is not extinguished, the air may be breathed safely for a short time. If the light goes out, it will be necessary before descending to let down dry-slacked lime, or pans of freshly-burned charcoal, to absorb the gas. When carbonic dioxide is brought into contact with

FIG. 181.



Pouring Carbonic Acid.

calcic hydrate solution (lime-water), the liquid turns milky, from the production of calcic carbonate. Thus, if we expose a saucer of lime-water to the air, in a short time its surface is covered with a thin film of calcic carbonate, proving that there is carbonic dioxide in the atmosphere. If we blow through a tube into a jar of lime-water, it quickly becomes turbid from the same cause, thus showing that there is carbonic dioxide in the expired breath. Under a pressure of 36 atmospheres at 32° F., carbonic dioxide shrinks into a colorless, limpid liquid lighter than water. When this pressure is removed, it does not suddenly resume its gaseous state, but evaporates with such rapidity, that one portion absorbs heat from another, and freezes it to a white solid, like dry snow. This solid carbonic dioxide wastes away but slowly, and may be handled, though, if it rests long upon the skin, it disorganizes it like red-hot iron.

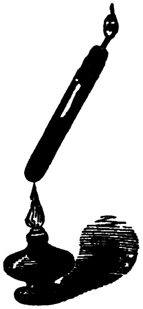
**491. Uses.**—The sparkling appearance and lively, pungent taste of various mineral waters are due to the carbonic dioxide they contain. Water absorbs nearly its own volume of carbonic dioxide, but by means of a forcing-pump it may be made to receive a much larger proportion. "Soda-water" is, ordinarily, only water charged with carbonic dioxide. Being overcharged, when the pressure is withdrawn, the gas escapes with violent effervescence. The effect is the same whether the carbonic dioxide is forced into the water from without, or generated in a tight vessel, as is the case with fermented liquors; the gas gradually formed is dissolved by the water, and, escaping when the cork is withdrawn, produces the fuming and briskness of the liquor.

Carbonic dioxide is also used to extinguish fires. In one case an English coal-mine, which had been on fire thirty years, was completely extinguished by pouring into it eight million cubic feet of this gas. In the "fire-annihilators" or "extinguishers," the gas is generated at the time when wanted, in a suitably-constructed metallic vessel, and discharged into the fire under pressure.

**492. Carbonic Disulphide,** $CS_2$.—This is a very volatile, colorless liquid, of about 1.27 specific gravity, which boils at 118.5° F. It has a peculiar, very unpleasant odor and pungent taste. It has never been frozen, and is used in thermometers which are to measure very intense degrees of cold. It is highly inflammable, burning with a blue flame, and yielding carbonic dioxide and hydric sulphate. It dissolves sulphur, phosphorus, and iodine, and is dissolved in ether, but not in water. It is produced by bringing vapor of sulphur into contact with red-hot charcoal, the compound vapor being condensed in cold vessels. From its high dispersive power over light, it is used to fill hollow prisms of glass for spectroscopic observations. It is also applied in chemical manufactures, to a variety of purposes.

**493. Cyanogen,** $C_2N_2$.—This substance may be best procured by heating mercuric cyanide ($HgC_2N_2$) in a glass tube or retort. The compound is decomposed, the cyanogen being evolved as a colorless gas, which may be ignited, burning with a beautiful blue flame, edged with purple, Fig. 182. Cyanogen is a transparent, colorless gas, poisonous if respired, and with a strong odor. It is very soluble in water, and hence must be collected in the pneumatic trough over mercury. It is reduced to a colorless, limpid liquid by a pressure of four atmospheres, and freezes into a transparent crystalline solid at 30° C.

FIG. 182.



Burning Cyanogen.

**494. Hydric Cyanide,** HCN (*Prussic Acid*).—This substance is found, in very small quantities, in the leaves, bark, blossoms, and fruit of the peach, cherry, sloe, and many other plants. It is best obtained by the decomposition of various metallic cyanides with a strong acid, and subjecting the mixture to distillation. Hydric cyanide, when pure, is at common temperatures a colorless liquid, which solidifies at 15° C., and boils at 26° C. It has the peculiar odor of bitter almonds or peach-blossoms. It is exceedingly poisonous, one drop producing instant insensibility, and almost instant death. The inhalation of the vapor should, therefore, be most carefully guarded against. The prussic acid of the shops is a more or less dilute solution of hydric cyanide, in water. The hydrogen of hydric cyanide is replaceable by simple or compound monad radicles, giving rise to a series of compounds termed cyanides.

**495. Potassic Cyanide,** KCN.—This compound is formed when potassium is heated in cyanogen gas, or hydric cyanide vapor, but it is obtained on a large scale by the decomposition of potassic ferrocyanide (yellow prussiate of potash) ($K_4FeC_6N_6$), by heat. It is a white crystalline body, very soluble in water, and exceedingly poisonous. It is much used in the arts in electroplating and gilding, and in the laboratory as a reagent.

## § 2. *Combustion.*

**496. Combustion a Chemical Process.** —Combustion, in its popular sense, is that form of chemical action which is accompanied by the disengagement of heat and light, and which usually takes place between the oxygen of the air and certain organic bodies, as wood, coal, oil, etc. The chemist, however, gives to the term a wider meaning, which includes all those forms of chemical action which result in the combination of bodies, with one or all of the constituents of a surrounding gaseous atmosphere; thus the violent burning of iron in oxygen, or its slow rusting in the air, the rapid consumption of wood in the furnace, or its gradual decay, are all alike, to him, cases of combustion. The nature of the gaseous atmosphere also makes no difference, and phosphorus or arsenic burning in chlorine gas, hydrogen, or iron in sulphur-vapor, are instances of this form of chemical action, as well as the corresponding changes taking place in air, or oxygen gas. Bodies were formerly divided into *combustibles* and *supporters of combustion*. Oxygen was held to be the universal supporter of combustion, while hydrogen, carbon, and iron, which burn in it, were called combustibles. But if the atmosphere were hydrogen, the so-called supporters of combustion would burn in it equally well, and the fact is, the action is mutual and of the same kind on the part of both.

**497. Rapid Combustion.**—The beginning of rapid combustion is termed *ignition*. In order to induce ignition a certain elevation of temperature is required, and the maintenance of this temperature is essential to the continuance of the combustion. After a substance is once kindled, the heat given off by the rapid chemical action is usually more than sufficient to maintain the combustion until the burning body is consumed. The temperature at which rapid combustion may take place differs with different bodies. Thus, in atmospheric air, phosphorus ignites at 150° F., sulphur at 480° F., while the hydrocarbons require a temperature of nearly 1000° F. to kindle them. The stability of the order of Nature depends upon the gradation of the affinities between atmospheric oxygen and the hydrogen and carbon of organic bodies. These are only brought into action at high temperatures. Did these bodies, like phosphorus, ignite at a much lower degree, conflagrations, which are now comparatively rare, would become universal.

**498. Explosive Combustion.**—When two gaseous bodies, combustible in each other, are mixed and ignited, an explosion ensues. This is because the constituents of the gaseous mixture are so intimately blended that the heat evolved by the particles first ignited passes to those adjoining, and so on through the entire mass, with such velocity as to cause an almost instantaneous completion of the process. The products of this form of combustion are always in the form of highly-expanded gases or vapors, the intense rarefaction of which gives rise to a vacuum, and the particles of air rushing in to fill this, in colliding with each other produce the noise of the explosion.

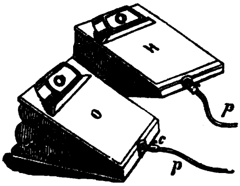
**499. Slow Combustion.**—Oxygen, as well as other elements, frequently enters into slow combination at ordinary temperatures and without perceptible heat, as in the rusting of iron in the air. The cause of decay in vegetable and animal substances is the slow action of oxygen. This slow combustion is termed *eremacausis.* Heat, however, always accompanies this slow form of combustion. An ounce of iron rusted in air, or burnt in oxygen, produces the same amount of heat, but in the former case it requires years for its development, and in the latter only as many minutes. Sometimes, under favorable circumstances, the combination becomes so rapid that the accumulated heat produces ignition, causing the phenomenon called *spontaneous combustion.* This is most liable to occur with porous substances which expose a large surface to the air. The tow or cotton used for wiping the oil from machinery, and then laid away in heaps, often ignites in this manner, especially if exposed to the sun.

**500. Heat of Combustion.**—The complete burning of a combustible body requires the consumption of the same quantity of oxygen, whether the process goes on rapidly or slowly, and, in either case, the amount of heat set free is the same. Therefore, the intensity of the heat depends upon the rapidity of the combustion. Heat would be liberated from the burning of a pound of coal in ten minutes, six times as fast as if its combustion occupied an hour. The burning in air of one pound of wood-charcoal will raise from the freezing to the boiling point 73 lbs. of water; one pound of mineral coal will correspondingly heat 60 lbs. of water; and one pound of dry wood will raise 35 lbs. of water through the same number of degrees. These are the highest results by careful experiments; in practice we obtain a much lower effect, both on account of imperfect combustion, and from the fact that a large proportion of the heated air escapes through the chimney, before it has given off as great an amount of heat as it is capable of producing.

**501. Cause of the Heat.**—It has been explained that chemical action produces heat by conversion of the motion of chemical atoms into heat-vibrations. We have atoms separated and powerfully attracted, like lifted weights; they rush together, collision arrests motion, and their force is given out as heat. It is the clash or impact of the atoms of oxygen against the elements of burning bodies, which gives us the heat and light of combustion. By figuring to ourselves the atoms shot across the molecular spaces with intense force, and thus parting with their motion, we have an explanation of the source of heat in combustion, which is in harmony with our latest knowledge of the nature of heat, and of its other modes of production, while in no other way is it possible to explain its chemical origin.

**502. Nature of Flame.**—Flame is produced by the combustion of gases. Substances which burn with flame are either gases already, or they contain a gas which is set free by the heat of combustion. But flame does not necessarily produce light. In the burning of pure oxygen and hydrogen, there is intense flame, but so little light that it can hardly be seen. If, into this non-luminous flame, we sift a little charcoal-dust, the particles of solid carbon are instantly heated to incandescence, and there is a bright flash of light. The conditions of illumination are, therefore, first, an intense heat; and, second, a solid placed in the midst of it, which remains fixed, and gives out the light.

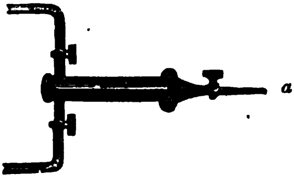
FIG. 188.



Gas-bags for Blow-pipe.

**503. The Compound Blow-pipe.**—These conditions are fulfilled most perfectly by means of the compound blow-pipe of Dr. Hare. The two gases are collected in gasometers, or India-rubber bags, Fig. 183, which are connected by flexible tubes with the brass jet, Fig. 184; the flow being increased by pressure on the bags, and controlled by stop-cocks. The gases are emitted together and burned at the orifice, *a*. When ignited, they give rise to a blue flame which is hardly visible, but which has intense heating power, and produces the most remarkable effects. A steel watch-spring burns in it with a shower of scintillations. Substances which do not fuse in the hottest blast-furnaces melt in this heat like wax, or dissipate in vapor.

FIG. 184.

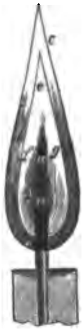


Blow-pipe Jet.

**504. The Lime-Ball.**—A little ball of lime, however, of the size of a pea, remains unaltered in the flame. It glows with a blinding brilliancy, producing what is known as the "Drummond light," or the "calcium light." It is employed as a substitute for the rays of the sun in the solar, or oxyhydrogen microscope, and is used in coast-surveys for night-signals. In all ordinary illuminations the principle is the same as that of the lime-light. The substances employed are compounds of carbon and hydrogen; the union of oxygen and hydrogen gives rise to heat, and the luminous carbon-particles at the same time set free in the heated space are the source of the light.

**505. How the Candle burns.**—The materials used for illumination, whether solids or liquids, are always converted into gas before burning. The candle first becomes a lamp, and then a gas-burner. When lighted, the heat radiates downward, so as to melt the material of the candle and form a hollow cup filled with the liquid combustible, Fig. 185, and thus the candle becomes an oil-burner. From this reservoir, the wick draws up the oil into the flame. Here, in the midst of a high heat, and cut off from the air, it undergoes another change exactly as if it were inclosed and heated in a gas-maker's retort; it is converted into gas, and in this form finally burned. As the wick rises into the flame, it fills the interior with a sooty mass, and interferes with the combustion.

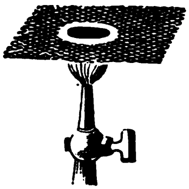
FIG. 185.



Burning Candle.

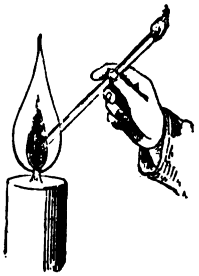
**506. Structure of the Flame.**—As the wick remains thus unconsumed in the interior of the flame, it is obvious there can be no fire there. If we lower a piece of glass or a wire gauze over a candle or gas flame, as in Fig. 186, we shall see an interior dark space surrounded by a ring of fire. This inner sphere is filled with dark unburned hydrocarbon vapors, which are inclosed by a shell of fire, or burning gas. If one end of a small glass tube be introduced into the candle-flame, as in Fig. 187, these interior gases will be conveyed away, and may be lighted at the other end.

FIG. 186.



The Flame hollow.

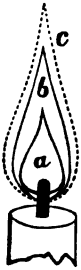
FIG. 187.



Gas from Flame.

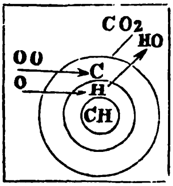
**507. Order of the Combustion.**—There is an order of combustion in the flame, which depends upon the order of affinities. In Fig. 188, *a* represents the nucleus of hydrocarbon vapor. If, now, oxygen from without had the same affinity for both its elements, they would be consumed together, with but little luminous effect. But the oxygen decomposes the gaseous compound, and, seizing upon the hydrogen first, surrounds *a* with the intensely heated space, *b*. At the same time the carbon-particles are set free, and, being heated white-hot, give out the motion of light. The cone *b* is therefore the place of burning hydrogen and the seat of illumination. The incandescent carbon-particles, as they pass outward, meet with oxygen at *c*, and are converted into carbonic dioxide in the outer cone. To prove the constant presence of free carbon in the flame, it is only necessary to introduce into it any cold body, as a piece of porcelain, when carbon will be copiously deposited upon it as soot. Fig. 189 represents a cross-section of the flame and the arrangement of its parts; CH the unburned carbon and hydrogen, H the sphere of burning hydrogen across which the carbon-particles float, and lastly the sphere of burning carbon. It will be observed, by noting any common flame, that at the base it burns blue, and yields but little light. This is because the oxygen at this point is so abundant that it burns simultaneously both hydrogen and carbon. A candle-flame moved swiftly through the air gives a diminished light for the same reason.

FIG. 188.



Shells of Flame.

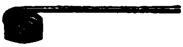
FIG. 189.



Cross-Section of the Flame.

**508. Effect of Temperature on the Flame.**—The amount of light produced depends upon the intensity of the heat. Dr. Draper found that a body at 2,600° emitted almost 40 times as much light as at 1,900°. If by any means the temperature of the flame falls below a certain limit it is immediately extinguished. The flame of a candle may be put out by lowering over it a coil of cold copper wire, Fig. 190. A piece of fine wire gauze held across the flame of a candle cools the combustible gases below the point of ignition, so that they rise through the meshes in the form of smoke, Fig. 191. The gauze may become red-hot and still not allow the flame to pass, so rapidly is the heat conducted away by the wire.

FIG. 190.

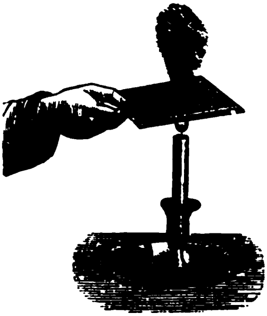


Copper Coil.

Yet the cooled gases may be rekindled above, when the flame will go on burning as before, Fig. 192.

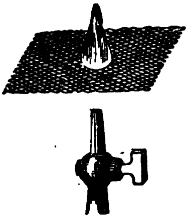
**509. Safety-Lamp.**—On this principle the safety-lamp is constructed. The explosions of hydric carbide in coal-mines caused immense destruction of life, and various arrangements had been fruitlessly contrived to prevent these terrible accidents when Sir Humphry Davy took hold of the subject. He commenced a series of researches upon flame in August, 1815, and with such success as to produce the perfected lamp at the Royal Institution of London in the succeeding November. The safety-lamp consists simply of an ordinary oil-lamp inclosed in a cage of wire gauze which permits the light to pass out, but prevents all exit of flame, Fig. 193. The space within the gauze often becomes filled with flame, from the burning of the mixed gases which penetrate the net-work; but the isolation is so complete that the explosive mixture without is not fired. Fatal explosions still occasionally take place, but they are due to carelessness of the miners. As the intensity of light depends upon the rapid consumption of oxygen, there must be a free supply of air, and provision for the escape of combustion products.

FIG. 191.



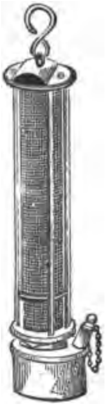
Gauze stops the Flame.

FIG. 192.



Gas burns above.

FIG. 193.



Safety-Lamp

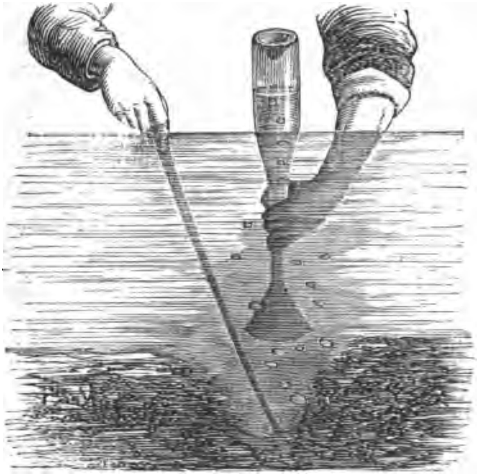
# DIVISION III.—ORGANIC CHEMISTRY.

## CHAPTER XXV.

### § 1. *Hydrocarbons and their Derivatives.*

**510. The Marsh-Gas Series (Paraffins).**—When the unit-weight of carbon combines with four unit-weights of hydrogen the result is the simplest known hydride of carbon, and since this is a saturated compound, or molecule, it is incapable of combining with chlorine, bromine, or any monad element, but it may exchange the whole or a part of its hydrogen for an equivalent quantity of another element. It is from these *hydrocarbons*, or compounds having this composition, that more or less directly the

FIG 194.



Marsh-Gas.

organic substances, to be hereafter described, may be built up.

*Methane*, $CH_4$ (*Marsh-Gas*), is the first member of a series, each term of which differs from the term next below by $CH_2$.

It is a colorless, inodorous, tasteless, inflammable gas, which burns with a yellow, luminous flame. If diluted with air, it is not injurious to life. It may be produced by heating in a glass flask a mixture of two parts of sodic acetate, three parts of potassic hydrate, and three of quicklime. It is called marsh-gas because it is a product of the decomposition of vegetable matter contained in the mud of stagnant pools. It may be collected by inverting a jar and funnel in the water, and stirring the mud beneath, Fig. 194, when the gas rises into the jar in bubbles. It is often disengaged in large quantities in coal-mines: mixed with the air it becomes explosive, and constitutes the fatal *fire-damp.* If the air is more than six times or less than fourteen times the bulk of the gas, the mixture explodes violently. Carbonic dioxide is produced by the combustion, so that those who are not killed by the burning or shock are generally suffocated by the choke-damp.

In some places, this gas rises from the earth in such quantities as to be utilized for purposes of illumination; as in the village of Fredonia, N. Y. In the deep wells sunk for brine and mineral oil, it often rises in such quantity as to be employed for driving the pumping-engines, or for evaporating the liquids.

*Petroleum* (*Rock-Oil*) is a natural product found on this continent, in Canada, and in Pennsylvania. In some cases it rises to the surface of the earth, but more generally it is obtained by sinking wells into the strata in which it occurs. It is a thick, greenish, oily liquid, of variable composition.

**511. Coal-Oil** consists, to a great extent, of a mixture of various compounds of the Paraffin Series. It is a product of the distillation of bituminous coal, bituminous shales, and asphalt. The material is placed in iron retorts, in large pits holding a hundred tons, or in kilns of brick containing twenty-five tons. The retorts are heated from without, like gas-retorts, while the kilns are fired within, like the tar-pits. The first product collected in the reservoirs resembles the natural oil from the wells, and is refined by the same method. It is first distilled at a temperature of 600° or 800° F., and the product, conveyed to cisterns holding 3,000 gallons, is agitated with 5 or 6 per cent. of hydric sulphate. The acid and settled impurities being drawn off at the bottom, the mass is again agitated, first with water, and afterward with alkaline lye; it is then redistilled, and constitutes the "*kerosene*" or "*petroleum-oil*" of commerce. It has been found by experience that it is not safe to use a paraffin-oil which will take fire on the application of a match, and burn continuously at a temperature below 100° F. The reason for this may be found in the fact that the oils obtained by the distillation of coal, at low temperatures, are mixtures of paraffins, differing in volatility, and unless the volatile members of the series have been driven off by proper distillation, the oils take fire easily, give off inflammable vapors which, mixing with air in the body of the lamp, form compounds which are dangerously explosive.

*Paraffin* is a crystalline, colorless, inodorous, tasteless, and fatty substance, probably a mixture of several of the higher terms of this series. It is found native in coal-beds and other bituminous strata, as fossil wax, mineral tallow, etc. It may also be procured from petroleum and from coal-oil. As it burns with a bright flame and is hard, it makes excellent candles. It is used as a substitute for sulphur in dipping matches, and to render woolen cloths stronger and water-proof.

**512. Olefine Series of Hydrocarbons.**—This series includes a number of interesting bodies. The lowest terms of the series are gaseous at ordinary temperatures; the highest solid, and the intermediate compounds liquid.

*Ethylene*, $C_2H_4$ (*Olefiant Gas*).—This gas may be prepared by mixing strong alcohol with five or six times its weight of sulphuric acid in a retort, and applying heat. It is colorless, tasteless, nearly as heavy as air, with a marked odor, very inflammable, and burns with a bright and intensely luminous flame. When mixed with air it is explosive, and derives its name (oil-former) from the fact that it forms an oily compound with chlorine. It was liquefied under great pressure by Faraday. It is decomposed by electric sparks into carbon and methane.

*Illuminating gas* consists of a mixture of various gases —hydrogen, methane, nitrogen, ethylene, carbonic monoxide and dioxide, and hydric sulphide being represented in the largest quantities. The illuminating power of the gas is nearly proportional to the quantity of ethylene which it contains. It is commonly produced from bituminous coal, placed in cast-iron retorts, fixed in furnaces, and heated to redness by an external fire. Each retort receives a charge of 100 to 150 lbs. of coal every six hours, and in large gas-works several hundreds of them are kept at work day and night. At a moderate heat, tar and oil are produced, but, at a high temperature, gases are formed in large quantities. Besides the products of this destructive distillation above mentioned, there are present a thick, black liquid, known as *coal-tar*, steam, various ammoniacal compounds and a solid, friable, carbonaceous mass known as *coke.*

Illuminating gas has come into use entirely within the present century, it having been first employed in London in 1802. How wonderful that sunbeams absorbed by vegetation in the primordial ages of the earth, and buried in its depths as vegetable fossils through immeasurable eras of time, until system upon system of slowly-formed rocks have been piled above, should come forth at last, at the disenchanting touch of Science, and turn the night of civilized man into day!

**513. Acetylene,** $C_2H_2$.—This compound is of special interest as a hydrocarbon which can be obtained by the direct union of its elements. It is formed when the current from a powerful battery passes, in an atmosphere of hydrogen, between carbon-poles. It is also the product of decomposition by heat or imperfect combustion of organic compounds.

**514. Turpentine Series.**—This series is interesting as including an isomeric group of the composition $C_{10}H_{16}$, called *Terpenes*, which occur, widely distributed through the vegetable kingdom, as the essential oils, to the presence of which the peculiar odor of certain plants is due.

*Terpenes*, $C_{10}H_{16}$.—The volatile oil of turpentine, also known as "spirits of turpentine," may be taken as a type of this class of substances. It is obtained by distilling with water the pitchy matter that exudes from various species of pine and other trees. Oil of turpentine is a colorless, limpid fluid, having a strong odor and disagreeable taste. It boils at 320° F., and has a specific gravity of 0·86. It is highly inflammable, and when purified is used for illuminating purposes, under the name of *camphene*. *Burning fluid* is rectified turpentine or camphene, dissolved in alcohol, which admixture renders it less smoky when burned. Spirits of turpentine is also used in varnishes as a solvent for resins and gums. The oils of lemon and orange are also terpenes.

**515. Benzine Series.**—The hydrocarbons of this class are found in coal-tar and in the petroleum which is obtained from Rangoon, in the kingdom of Burmah. *Benzol*, or *benzene* ($C_6H_6$), is very much used in the arts. It is a colorless, volatile liquid, the vapor of which is very inflammable. It burns with a smoky flame. Benzol is valuable as a solvent, readily dissolving phosphorus, sulphur, and caoutchouc, as well as wax and all fatty bodies.

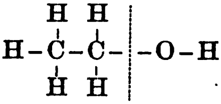
By the action of nitric acid on benzene, a heavy oily liquid called *nitro-benzene* is produced. It has an odor resembling that of bitter almonds, and is used in perfumery, but it is chiefly interesting as being a stepping-stone in the production of *aniline*, $C_6H_7N$, which has of late years acquired special importance as the basis of the well-known aniline colors. Aniline is obtained indirectly from benzene, one of the chief constituents of coal-tar, though it also occurs in the coal-tar, ready formed, in small quantities. It is a colorless, mobile, oily liquid of faint, agreeable, vinous odor, and aromatic, burning taste. It boils at 182° C., solidifies at very low temperatures, is easily soluble in alcohol and ether, and slightly soluble in water. It is poisonous.

*Naphthalene*, $C_{10}H_8$, closely resembles benzene in chemical reactions. It is a product of the decomposition of many hydrocarbons by a red heat, and is obtained abundantly in the distillation of coal-tar. It is solid at ordinary temperatures, insoluble in water, but dissolves in alcohol.

**Anthracene**, $C_{14}H_{10}$, is a white solid, and is one of the last products of the distillation of coal-tar. It has lately attracted much attention owing to the fact that *alizarine*, the red coloring substance of the madder-roots, has been obtained from it. *Carminic acid*—the coloring-matter of cochineal—is used for dyeing wool and silk crimson or scarlet, but the colors, though brilliant, are not durable.

## § 2. *Alcohols.*

**516.** The term *alcohol*, which originally designated only one substance, viz., spirit of wine, has now a much wider meaning, and is applied to quite a large number of compounds, many of which in their external characteristics exhibit but little likeness to common alcohol. They are all compounds of oxygen, hydrogen, and carbon, and may be regarded as derived from the hydrocarbons of the marsh-gas series by substituting for a single atom of hydrogen the radicle hydroxyl (HO), as, for example, common alcohol.



$$\begin{array}{c|c} \begin{array}{ccccc} & H & & H & \\ & | & & | & \\ H- & C & - & C & - \\ & | & & | & \\ & H & & H & \end{array} & -O-H \end{array}$$

*Methyl Alcohol*, $CH_4O$ (*Wood-Spirit*).—This is one of the chief products of the dry distillation of wood. When pure it is a thin, colorless liquid, very similar in smell and taste to common alcohol. Crude wood-spirit, however, is always impure, has an offensive odor, and a nauseous, burning taste. It is employed in the arts for many of the purposes for which ordinary alcohol is used, especially in the manufacture of varnishes.

**517. Ethyl Alcohol**, $C_2H_6O$ (*Common Alcohol, Spirits of Wine*).—When solutions of sugar ($C_{12}H_{22}O_{11}$), or the sweet saccharine juices of plants, are acted upon by ferments, they are decomposed, with evolution of carbonic dioxide, and formation of alcohol. This substance may also be obtained from ethylene; ethylene may be prepared from acetylene (513), and thus it will be seen that it is possible by a series of simple reactions to build up alcohol from the elements carbon, oxygen, and hydrogen. It is a colorless, mobile fluid, of 0.77 specific gravity, having a pleasant, fruity smell, and a burning taste. It is very volatile, and has a strong tendency to absorb moisture from the air or from bodies immersed in it, thus rendering it valuable as an antiseptic. It is highly combustible, burning with a pale-blue flame, and producing intense heat without smoke; it is therefore well adapted to burn in lamps for chemical use. Alcohol has great value as a solvent, as it acts upon many substances which water does not dissolve, and is easily separated from them on account of its extreme volatility. It boils at 173° F., and has never been frozen, although at —166° it becomes viscid. In a concentrated form it is a potent poison, but, when sufficiently diluted, it acts upon the animal system as a stimulant. Taken freely in this form it produces inebriation, and is the active principle of all intoxicating liquors.

**518. Amyl Alcohol,** $C_5H_{12}O$ (*Fusel Oil*).—This alcohol is produced together with ordinary alcohol in fermentation. It is a transparent, colorless liquid, of unpleasant, mouldy, spirituous odor, and burning taste, and is poisonous. It burns with a white, smoky flame, and has been used for illuminating purposes.

**519. Wines** are obtained from the expressed juice of the grape and other fruits. The fresh grape-juice, or *must*, is placed in vats in cellars, where the temperature is so low that the fermentation proceeds very slowly. Sometimes the wines are bottled before the fermentation is quite complete, and they continue to generate carbonic dioxide, which remains compressed within the liquid. If the carbonic dioxide is so abundant as to produce effervescence when uncorked, the wine is said to be "*sparkling;*" if otherwise, it is termed "*still*" wine.

**520. Lager-Beer** is freed from nitrogenized products by a slow and long-continued fermentation; hence it may be preserved for years without further decomposition. Before consumption it lies stored in vaults for months, from which circumstance its name is derived (*lager*, lair). The difference in color of malt liquors is owing to the various degrees of heat employed in malting. *Ale* is made from pale malt, while that used for *porter* is partially charred, giving it a brownish color and bitter flavor.

**521. Distilled Liquors** are obtained by subjecting certain fermented mixtures to distillation. *Brandy* is derived from the distillation of wine; *rum* from that of fermented molasses, and *arrack* from the distillation of fermented rice-infusion. *Whiskey* is obtained from corn, rye, and potatoes, by first converting their starch into sugar, then into spirit, and distilling the product. *Gin* is produced from the distillation of the spirit of a mixture of barley and rye, and owes its peculiar flavor to juniper-berries.

**522. Phenol,** $C_6H_6O$.—A substance familiarly known as carbolic acid is regarded by the chemist as the alcohol of benzene:

Benzene, $C_6H_6$. Phenol, $C_6H_5OH$.

The chief source of phenol is coal-tar, from which it is obtained by distillation. Pure phenol crystallizes at ordinary temperatures in long, colorless, needle-shaped prisms, which attract moisture from the air, deliquescing to an oily hydrate. The crystals melt at 35° C., and boil at 180° C., are slightly soluble in water, more freely in alcohol. They have a penetrating, smoky odor and a burning acrid taste. Phenol and its solutions have in an eminent degree the property of preserving animal substances from decay, and are on this account much employed as antiseptics and disinfectants. A considerable portion of the creosote of commerce consists of phenol. Genuine creosote is a colorless, oily liquid with a smoky odor and burning taste. It is a powerful antiseptic, and meat, steeped for a few hours in a solution of one part creosote to 100 parts water, remains sweet and will not putrefy. Creosote is used very extensively in medicine, both inwardly and as an external application, but an overdose is a corrosive poison. Crude pyroligneous acid, on account of the creosote it contains, is used to preserve meats, to which it imparts a smoky flavor. The curing quality of the smoke of green wood is also owing to this cause. It is the vapor of creosote which renders smoke so irritating to the eyes.

**523. Fats and Oils.**—Most of the fixed oils, and the fats, both animal and vegetable, are compounds of glycerine, and acids of the acetic and oleic type. Thus beef and mutton fat consist mainly of stearic glyceride (stearin); olive-oil is oleic glyceride (olein); palm-oil is chiefly palmitic glyceride (palmitine). These glycerides, when decomposed, by heating with water yield glycerine and an acid.

*Glycerine* ($C_3H_8O_3$).—When pure this substance is a nearly colorless, inodorous, sirupy liquid, of intensely sweet taste. It is readily soluble in water and alcohol, and is a powerful solvent and antiseptic. Of late years, it has been employed as a medicine; and, on account of its solvent power, it is also largely used as a vehicle for administering other medicines. It is extensively employed in the manufacture of cosmetics and perfumery. Glycerine is nonvolatile, and, when heated over 600° F., is decomposed, giving off among other products a peculiar acrid substance termed *acroleine* ($C_3H_4O$). This is the body which causes the irritating fumes of a smouldering candle-wick and of burning fats when the combustion is incomplete.

**524. Nitro-glycerine,** $C_3H_5(NO_3)_3$.—When a mixture of strong sulphuric and nitric acids acts on glycerine, at low temperatures, a violently explosive, oily liquid of light-yellow color is produced. This compound has a specific gravity at 15° C. of 1.6, is inodorous, but has a sweet, pungent, aromatic taste, and, placed upon the tongue, produces headache. Nitro-glycerine is exploded not by the direct application of heat, but by sudden concussion, and proper care in its preparation greatly lessens the danger accompanying its use.

## § 3. *Saccharine Bodies.*

**525.**—Saccharine bodies, sometimes called carbo-hydrates, constitute an important class of substances, interesting on account of their wide distribution in the vegetable world. Among these substances we have the sugars proper, grape-sugar, gum, starch, and woody fibre. These are probably related to the alcohols, though their exact composition has not in all cases been ascertained. Two of these compounds, grape and fruit sugar, break up into alcohol and carbonic dioxide under the influence of yeast. *Dextrose*, or *grape-sugar*, $C_6H_{12}O_6$, is widely distributed in all ripe fruits, and may be prepared by boiling starch in dilute sulphuric acid. Isomeric with this compound is *lævulose*, or *fruit-sugar*, which occurs mixed with other varieties of sugar in the juices of ripe fruit, honey, etc. Both of these compounds belong to the group of *glucoses*.

**526. Cane-Sugar,** $C_{12}H_{22}O_{11}$, is produced chiefly from the cane, beet-root, sorghum, and the palm and maple trees; but by far the largest portion is from the sugar-cane. The canes are crushed by passing them between grooved iron cylinders. The juice, when first expressed, is liable to rapid decomposition from the heat of the climate. This is prevented by the addition of a small quantity of lime, which neutralizes acids and coagulates impurities. The juice is evaporated by boiling in large, open vessels, and, when reduced to a proper consistency, is transferred to coolers, where a portion of it crystallizes, forming raw or brown sugar. On an average, a gallon of juice produces a pound of sugar.

Crude sugars are purified, or refined, by reducing them to a sirup, which is first filtered through twilled cotton, to separate mechanical impurities. The same effect is further promoted by the use of serum of blood. To decolorize the sirup it is again filtered through a bed of coarsely-powdered bone-black or animal charcoal. It is then evaporated in vacuum-pans—the air being exhausted, so that it will boil at a lower temperature—and finally recrystallized. The drainage of the raw sugar forms molasses.

**527. Properties.**—Pure cane-sugar has a specific gravity of 1.6, is soluble in about one-third of its weight of cold water, forming a thick sirup, and separates from concentrated solutions in large, transparent, colorless crystals, having the shape of oblique rhombic prisms or modified forms. It melts at about 320°C., and solidifies, on cooling, to a transparent, amber-colored substance, known as barley-sugar. If the melted sugar be heated to 420°C., it changes to a dark-brown mixture of several different bodies, which is termed caramel, and is much used for coloring sirups and liquors.

**528. Lactose** (Milk-Sugar), $C_{12}H_{22}O_{11} + H_2O$, is obtained only from the milk of the mammalia, to which it gives the sweetish taste. It is obtained by evaporating clarified whey till it crystallizes. It is much less soluble, and therefore much less sweet, than cane-sugar, and its crystals are hard and gritty. It is much used in the preparation of homœopathic medicines.

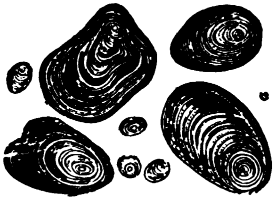
**529. Gum,** $C_{12}H_{22}O_{11}$ (*Arabin*).—These terms are applied to a class of substances which are often seen exuding in globular masses from the bark of trees, as the plum and cherry. Gum is translucent, tasteless, inodorous, and either dissolves in water, or swells up and forms with it a thick mucilage. It exists in small proportion in the cereal grains, but its chief source is certain tropical trees, from the bark of which it flows in such quantity as to be gathered for commercial purposes. *Gum-arabic*, the product of a species of acacia, is a hard, brittle substance, and is, perhaps, the best known of the gums. Its solution being very adhesive, is used as a substitute for paste or glue. *Mucilage* or *bassorin* is a kind of gum insoluble in water, but which swells into a gelatinous mass when moistened. It abounds in gum-tragacanth, and also in quince-seeds and linseed. *Pectin*, or the jelly of fruits, is in its physical properties closely allied to the gums, but its exact chemical composition has not yet been established with certainty.

*Balsams* are complex substances which exude from the bark of certain trees; they consist for the most part of an essential oil which holds in solution peculiar substances known as *resins*. Gum-copal, mastic, and shellac, belong to this class; they are insoluble in water, but dissolve in alcohol, naphtha, and oil of turpentine. The solutions thus formed constitute *varnishes.*

**Caoutchouc,** or India-rubber, is a compound of hydrogen and carbon, of great value to the chemist. It is the hardened juice of several tropical trees, and when pure is white. Combined with sulphur in variable proportions it forms the vulcanized caoutchouc or vulcanite of commerce.

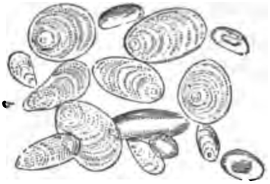
**530. Starch,** $C_6H_{10}O_5$. — This substance is found universally distributed in the vegetable kingdom in grains, seeds, roots, and the pith and bark of plants. When pure it is a snow-white, glistening powder. Examined by the microscope, it is found to consist of exceedingly minute round or oval grains, which vary in size from $\frac{1}{100}$ to $\frac{1}{10,000}$ of an inch in diameter. The starch-granules of potatoes are much larger than those of wheat or rice. Starch-grains from different sources vary also in form and structure. Those of the potato are egg-shaped; those of wheat are lens-shaped; those of rice angular; while several kinds have a grooved aspect, and consist of concentric layers, like the coats of an onion. As each variety has some peculiarity by which it may be identified, the adulteration of wheat-flour by potato, or other starches, may thus be detected.

FIG 195.



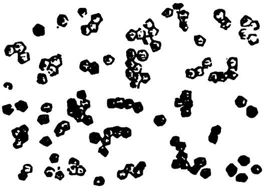
Starch-Grains of Potatoes.

FIG. 196.



Starch-Grains of Plantain.

FIG. 197



Starch-Grains of Rice

**531. Properties and Uses.**—Starch is insoluble in cold water, alcohol, and ether, but swells up and is converted into a paste in water containing 2 per cent. of alkali. If heated in water to 140° F., the grains swell and burst, producing a jelly-like mass (gelatinous starch, or *amadin*), which is used to impart a gloss to textile fabrics. The test of starch is iodine, which combines with it, forming a blue compound. The uses of starch are varied; the most important, however, is that of nutrition, the comparative value of different articles of vegetable diet depending largely on the proportion of this proximate principle which they contain. When vegetable food is prepared for the table by the various processes of cooking, the starch is slightly modified.

**532. Dextrine.**—When commercial starch is heated under pressure to 400° F. for some hours, it becomes soluble in cold water, and is changed into a gummy substance called *dextrine*, which, under the name of British gum, has been successfully substituted for gum-arabic by calico-printers in thickening their colors. Dextrine is also produced when starch-paste is boiled for a few minutes with weak sulphuric acid. It is a transparent, brittle solid, isomeric with starch, soluble in water, incapable of fermentation, and produces *right-handed* rotation in a ray of polarized light; hence its name. When solutions of dextrine are boiled with dilute acids for some hours, the dextrine is converted into glucose. Dextrine is also formed from starch, by the action of animal secretions such as saliva, bile, and pancreatic juice.

*Glycogen*, $C_6H_{10}O_5$, was first obtained by Bernard from the livers of animals. It is a white, amorphous, starch-like substance, odorless and tasteless, and is converted into glucose by boiling with dilute acids, or by contact with blood, saliva, or pancreatic juice.

*Inulin* is a substance obtained from the roots of many plants, among which are the dahlia, dandelion, and chiccory. It has the same composition as common starch, but differs from it in some important particulars. Inulin may be obtained by washing the rasped roots on a sieve, when it will settle to the bottom of the liquid. It is a white, tasteless substance, which is not soluble in cold water, but freely dissolves by the aid of heat. It exists in the plant in a liquid form, and is converted by the action of dilute acids into lævulose. Iodine does not turn inulin blue.

**533. Cellulose,** $C_{18}H_{30}O_{15}$ (*Woody Fibre, Lignine*).—This is the most abundant product of vegetation. Besides forming the chief bulk of all trees, it exists in the straw and stalks of grain, in the membrane which envelops the kernel (bran), in the husk and skin of seeds, and in the rinds, cores, and stones of fruit. Wood consists of slender fibres, or tubes closely packed together. When first formed these tubes are hollow and serve to convey the sap, but in the heart-wood of trees they become filled up and consolidated, the circulation of fluids taking place in the white external sap-wood (*alburnum*). Upon the density with which the fibres are imbedded depends the property of hardness or softness of wood. Cellulose is the fibrous portion of the woody tissue.

**534. Properties and Uses.**—The properties of cellulose may be conveniently studied in fine linen and cotton, which are almost entirely composed of it. When pure it is tasteless, insoluble in water and alcohol, and not sensibly affected by boiling water. By cold concentrated sulphuric acid, it is converted into dextrine. The uses of cellulose are almost numberless. It forms the chief bulk of the wood we burn, of the linen and cotton fabrics we wear, and of the paper we write and print upon. Besides these uses of unaltered cellulose, a multitude of useful chemical bodies are derived from its decomposition; charcoal, illuminating gas, tar, wood-spirit, wood-vinegar, creosote, and oxalic acid, being among the most important. Grape-sugar and alcohol have also been made from it.

**535. Pyroxylene.**—If pure cellulose ($C_{18}H_{30}O_{15}$), as cotton, linen, sawdust, or paper, be steeped for a few minutes in a mixture of nitric and sulphuric acids, then squeezed, washed, and dried by gentle heat, a part of the hydrogen of the cellulose is oxidized by the action of the nitric acid, and eliminated as water, while its place in the compound is occupied by a corresponding quantity of the radicle nitryl $(\overset{v}{N}O_2)$. This quantity is greater in proportion to the concentration of the acid. When a mixture of concentrated sulphuric acid with nitric acid of 1.52 specific gravity is used, pyroxyline, $C_{18}H_{21}(N_2O_2)_9O_{15}$, a highly-explosive compound, is produced, which constitutes the well-known *gun-cotton*, discovered a few years ago by Prof. Schönbein. It ignites at 400° F. (200° below gunpowder), and disappears in an instantaneous flash, leaving hardly a trace of residue. Authorities vary in estimating its explosive force, but the latest make it about three times that of gunpowder. The extreme suddenness of the propulsive force overstrains the gun and produces less effect upon the ball than gunpowder. *Collodion* is formed by dissolving gun-cotton in ether, containing a small proportion of alcohol. On evaporating the ether, a transparent, adhesive film is left, which is insoluble in water and is used in surgery for protecting wounds from the air. The chief use of collodion, however, is in photography.

## § 4. *Fermentation.*

**536.** When certain compound substances, derived chiefly from plants and animals, are exposed to the action of air and water, at a given temperature, they undergo decomposition, which, when involving the formation of useful products, is generally known as *fermentation*, but when resulting in the production of useless and ill-flavored bodies is distinguished as *putrefaction*. These changes all agree in having a peculiar self-sustaining and contagion-like character. The true nature of these processes is not yet thoroughly understood. But careful investigation has shown that, in by far the largest number of cases, we may recognize the presence of *living organisms.* The exciting cause of fermentation has been sought in the oxygen of the air, but it appears from recent experiments that air which has been passed through a red-hot tube does not induce fermentation even in those bodies which are most liable to this change. It has been proved, however, that ordinary air contains the germs of microscopic plants and animals, and it seems almost certain that the excitation of the processes in question is due to their action.

**537. Ferments and Fermentable Bodies.** — The substances most disposed to putrefaction are certain compounds rich in nitrogen, contained largely in flesh, blood, cheese, milk, white of egg, gelatine, and other animal products. These bodies require only the presence of water, and free access of air at the commencement, to induce in them a process of decomposition. Of those compounds which contain no nitrogen there are but few, as for example sugar, gum, and starch, that may be brought into a state of fermentation by mere contact with air and water. But many substances, incapable of fermenting by themselves, undergo that change when brought in contact with a minute quantity of the above-mentioned nitrogenous bodies. The latter are, for this reason, termed *ferments*, the former *fermentable bodies.*

As a spark may kindle a conflagration that shall consume a city, so the minutest quantity of fermenting or putrescent matter is often sufficient to affect an indefinite quantity of changeable substance. The remarkable communicability of these effects is well observed in the action of leaven upon dough. It is also painfully illustrated by physicians, who sometimes wound themselves while dissecting. The small trace of decomposing matter from the dead body which clings to the dissecting-knife is sufficient to establish a rapid decomposition in the living system, which, in many cases, quickly terminates in death.

The part played by yeast, and the nature of vinous fermentation, has been a matter of much speculation. Yeast consists of round or egg-shaped cells about $\frac{1}{1000}$ of a millimetre in diameter; these consist of an outer wall of cellulose, inclosing a liquid. The yeast-cells grow and multiply in a fermenting liquid, but the presence of nitrogen, phosphorus, sulphur, potassium, and magnesium, in combined form, seems to be necessary to their growth. Several different kinds or modes of fermentation have been observed, varying in the character of the products formed. The processes are, moreover, very much modified by temperature and other atmospheric conditions. The modes of fermentation best known are the vinous, acetous, lactous, and saccharous.

**538. Vinous Fermentation.**—When the sweet juice of fruits or plants is exposed to the air at the temperature of 70° or 80° F., in the course of a few hours a change commences: small bubbles consisting of carbonic dioxide rise to the surface, the liquid becomes turbid, and begins to ferment, or, as is commonly said, to "*work.*" After a time the bubbles cease to rise and the liquid is no longer sweet, but has acquired a spiritous taste. If, now, it be distilled, an inflammable body is separated, which is known as *spirits of wine*, or *alcohol*, a product of the decomposition of sugar. Besides the alcohol the fermented liquid generally contains two other bodies, known respectively as *glycerine* and *succinic acid.* Other compounds are also in some instances produced.

**539. Saccharous Fermentation.**—But sugar itself may be a product of fermentation. When seeds are exposed to air and moisture at a suitable temperature, germination commences. This consists in a series of changes, of which the first is an alteration of a portion of the nitrogenous matter and the production of a compound not well understood, called *diastase.* This is an active ferment, and, taking effect upon the starch, changes it to sugar and dextrine. When barley is treated in this way it swells and becomes sweet. Diastase is formed, and the barley is termed *malt.* When the germ is about half an inch long the process is arrested by heat, but the dextrine is not destroyed.

**540. Acetous Fermentation.**—If the vinous fermentation is not checked at the proper time, it passes on to a second stage, the *acetous fermentation;* the liquid loses its spirit and quality, and becomes *sour.* Oxygen is absorbed, and the alcohol converted into vinegar or *acetic acid*, $C_2H_4O_2$. Pure diluted alcohol does not absorb oxygen when exposed to the atmosphere; it is affected only by adding some matter in a state of change, or which absorbs oxygen. The action proceeds slowly at first, but by degrees a peculiar body, a kind of slimy vegetable mould, is formed, which is known as *mother of vinegar*, and which acts something like a ferment to hasten the process. It is supposed that this acetous ferment acts as a carrier of atmospheric oxygen, which it absorbs within its pores, thus bringing it into intimate contact with the alcohol. In this respect the action of the ferment is like that of platinum, which causes the union of oxygen and hydrogen, when these gases are condensed within its pores.

## § 5. *Ethers and Aldehydes.*

**541.** The ethers may be regarded as oxides of the alcohol radicles, and they bear the same relation to the alcohols that metallic oxides bear to the metallic hydrates, thus:

$$\left.\begin{matrix}C_2H_5\\C_2H_5\end{matrix}\right\}O$$

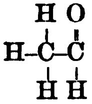
Ethylic Oxide.
(Ethylic Ether.)

$$C_2H_5.\ OH$$

Ethylic Hydrate.
(Ethylic Alcohol.)

*Ethylic Ether*, $C_4H_{10}O$ (*Sulphuric Ether*).—When equal weights of strong sulphuric acid and alcohol are heated in a retort, a vapor passes over which may be condensed into a limpid fluid, called *ether* from its volatility, and *sulphuric ether*, because in obtaining it sulphuric acid is employed. Ether is colorless, with a fragrant odor, a hot, pungent taste, and, when inhaled, produces insensibility to pain; hence it is much used as an anæsthetic. It is so volatile that it disappears when poured through the air from one vessel to another, and, when placed upon the hand, produces cold by rapid evaporation. It boils at 96° Fahr., or when exposed to the air in summer, and is very combustible, burning with more light than alcohol and some smoke. Its vapor, when mixed with air, is explosive. It readily dissolves fats and oils.

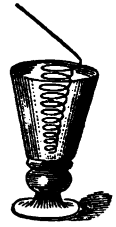
**542. Aldehydes.**—The aldehydes are a class of compounds intermediate between acids and alcohols, and they are produced by the oxidation of the latter. Example, acetic aldehyde:



$$\begin{array}{ccc} & H & O \\ & | & \| \\ H- & C- & C \\ & | & | \\ & H & H \end{array}$$

*Acetic aldehyde*, $C_2H_4O$, the best known compound of this series, may be produced by the gradual oxidation, in various ways, of ordinary alcohol, or by transmitting a mixture of alcohol and air through a porcelain tube at a low red heat. When a few drops of alcohol are placed in a cup, its vapor will mingle with the air. If, now, a red-hot coil of platinum wire be introduced into the cup, Fig. 198, the oxidation of the vapor commences, pungent odors of acetic aldehyde are given off, and the wire is kept at a red heat by the continued oxidation. If the coil be suspended over the wick of an alcohol or ether lamp, Fig. 199, it will continue to glow for hours after the flame is extinguished, from the

Fig. 198.

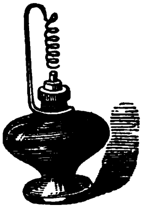


Oxidation of Alcohol.

same cause. Acetic aldehyde is a highly-volatile, inflammable liquid, with a pungent, apple-like odor.

**543. Camphor,** $C_{10}H_{16}O$.—This well-known substance has the composition of an aldehyde, but its reactions are different from the other aldehydes. It is obtained by distilling the wood of the camphor-tree (found in Japan and other parts of the East) with water, and collecting the vapors in a vessel containing rice-straw. It condenses in the straw and is again sublimed, after which it is thrown into commerce; but it requires subsequent purifications to fit it for use. Camphor is quite volatile and readily soluble in alcohol, with which it forms a solution known as *spirits of camphor.* Taken in large doses it acts as a poison.

FIG. 199.



Flameless Lamp.

**544. Chloral,** $C_2HCl_3O$.—By replacing a single atom of the hydrogen in the formula of aldehyde, by chlorine, the formula for a compound known as *chloral* is obtained. It is formed by the action of pure and dry chlorine gas on absolute alcohol. It is a thin, colorless oil, which boils at about 96° C. It has a peculiar, pungent odor, and excites a copious flow of tears. Its taste is greasy, and slightly astringent. The vapor acts powerfully upon the skin. Mixed with a small quantity of water it becomes heated and solidifies to a white crystalline mass, *chloral hydrate,* which is soluble in a large quantity of water, volatilizes gradually in the air, and may be distilled without decomposition. It has been recently introduced into medicine, as a means of producing sleep.

**545. Chloroform,** $CHCl_3$, is prepared by distilling alcohol with a solution of chloride of lime. It is a colorless, volatile liquid, of a strong, agreeable odor, and a sweet, penetrating taste. It dissolves sparingly in water, but freely in alcohol and ether. It is extensively employed in medicine, but for this purpose it should be perfectly pure, as the fatal effects which have sometimes attended its use are doubtless chiefly owing to its contaminations. It should be colorless and free from a chlorous smell, or any unpleasant odor, when a few drops are evaporated on the hand.

Chloroform is one of the most important representatives of a class of bodies, the vapor of which when inhaled produces temporary insensibility to pain, or *anæsthesia;* these substances are known as *anæsthetics.*

# CHAPTER XXVI.

## ORGANIC CHEMISTRY (CONTINUED).

### § 1. *Acids.*

**546.** A LARGE number of organic acids are known, some of which exist in a free state, as, for example, formic acid, which is secreted by ants and is found in nettles. These compounds constitute several series, which are all regarded as derived more or less directly from the hydrocarbons. *Formic acid*, $CH_2O_2$, is a clear, pungent, volatile, strongly acid liquid, which was first obtained by distilling the bodies of red ants (*Formica rubra*) in water, hence its name *formic* acid. It is also found in human blood, urine, and other secretions, in the juices of many plants, and in the waters of certain mineral springs.

**547. Acetic Acid,** $C_2H_4O_2$.—This acid is one of the most important organic compounds. It is the essential constituent of vinegar, which is merely a more or less impure solution of acetic acid, common table-vinegar containing from three to four per cent. Pure acetic acid is, at ordinary temperatures, a colorless, intensely sour liquid, having a pungent odor, and capable of raising a blister on the skin. It solidifies at or below 17° C. to a crystalline, ice-like body, known as "glacial acetic acid," and boils at about 119° C. *Vinegar* is usually obtained by the spontaneous oxidation of dilute alcoholic liquors, saccharine solutions, etc. If, in the process of its manufacture, the air comes in contact with only a small portion of the liquid, months may be required to produce the change. *Wood-vinegar*, or pyroligneous acid, is obtained by the destructive distillation of wood, dry beech-wood being the best, a pound yielding nearly half a pound of the acid. It is a brown liquid, with a strong smoky taste and odor. It is extensively used to form salts—the acetates used by dyers.

**548. Butyric Acid,** $C_4H_8O_2$, is prepared by allowing a mixture of sugar, chalk, and cheese, to ferment. It is found in small quantity in butter, in perspiration, in some plants, and in the juice of human flesh. It resembles acetic acid in appearance, has a peculiar rancid odor, and is soluble in water.

*Glycocholic Acid*, $C_2H_4O_3$, constitutes the great mass of the resinous matter of ox-bile; it forms silky white, needle-shaped crystals, of a bitter-sweet taste, which are soluble in water and alcohol, and have an acid reaction.

**549. Lactic Acid,** $C_3H_6O_3$.—This acid is so called because it occurs in sour milk. It is formed from sugar by *lactic fermentation*, and is a colorless, sirupy, very acid liquid. *Succinic acid*, $C_4H_6O_4$, is also one of the products of the fermentation of sugar (538), and is obtained by the distillation of amber. It occurs in certain resins, in wormwood, and in small quantities in animal juices. Intimately connected with this acid are two of much importance, viz., *malic acid*, $C_4H_6O_5$, and *tartaric acid*, $C_4H_6O_6$. The former is found in many acid fruits and in the stalks of rhubarb, but is usually obtained from the unripe berries of the mountain-ash. It is a colorless solid, dissolves readily in water and alcohol, and crystallizes with difficulty. The solutions of all the acids named have an agreeable acid taste, but become mouldy if long kept, and gradually undergo decomposition.

*Tartaric acid* is found abundantly in the juices of many fruits. It is obtained by the decomposition of calcic tartrate with sulphuric acid. Its crystals, when pure, are colorless, transparent, permanent in the air, and dissolve readily in water or alcohol. It is extensively used by the calico-printer and dyer for the removal of mordants. Mixed with the bicarbonates of the alkalies, it forms the soda-powders of effervescing draughts.

**550. Benzoic Acid,** $C_7H_6O_2$, obtained exclusively at one time from gum-benzoin, is now procured from *hippuric acid*, which occurs in the urine of herbivorous animals.

**551. Salicylic Acid,** $C_6H_4$ OH $CO_2H$, is one of the derivatives of *salicine*, which is a neutral vegetable principle, discovered in 1830 in the bark of the willow, *Salix*, whence its name. The acid was early obtained from the flowers of the meadow-sweet (*Spirea ulmaria*), and it occurs in the oil of winter-green. It is now regarded with great interest, on account of its valuable qualities as an anti-ferment and antiseptic. As its practical value became known, the sources from which it had been obtained were found utterly inadequate to the increased demand; and the reconstructive power of the modern chemist sought for a compound, which might be split up, or reorganized in such a way as to yield the desired salicylic acid. The German chemists found this in phenol or carbolic acid, a substance long known for its valuable qualities as an anti-ferment. The agent selected to reconstruct the molecule of phenol was carbonic dioxide. The pure acid is obtained in minute acicular crystals, white, odorless, and nearly tasteless; insoluble in cold water, more soluble in hot water, and in still greater degree soluble in alcohol and ether. It melts at about 257° F. It is used in medicine and in surgical operations, where it is said to be more effective in smaller quantities than any other antiseptic, and to be devoid of all irritating action upon the living tissues. In cases of decomposition which cannot be reached by any other antiseptic, salicylic acid is claimed to be especially valuable.

**552. Citric Acid,** $C_6H_8O_7$, is found principally in fruits of the orange family, but is of frequent occurrence in gooseberries, currants, and other acid fruits. It may be readily procured from the juice of the lemon by the aid of chalk and sulphuric acid. It has a pleasant acid taste, is very soluble in water, and is used in medicine, calico-printing, and for effervescing draughts. *Gallic acid,* $C_7H_6O_5$, occurs in sumach, acorns, tea, and many plants. It crystallizes in silky needles, is freely soluble in boiling water, and does not precipitate gelatine. Heated to about 215° C., gallic acid is decomposed into carbonic dioxide and pyrogallol, $C_6H_6O_3$. This acid is extensively used in photography. Both gallic acid and pyrogallol decompose the salts of silver, gold, and platinum; hence they are extensively employed in photography, and in the manufacture of hair-dyes.

**553. Tannins (Tannic Acids).**—There are several distinct compounds known under the name *tannin,* which resemble each other in character and possess an acid reaction. They are found extensively diffused throughout the vegetable kingdom, and are all distinguished by an astringent taste. The bark and leaves of most forest-trees, as well as of many fruit-trees, contain a large quantity of tannin; it is found in various roots, shrubs, and seeds, and is the astringent principle of tea and coffee. The most important of these compounds, obtained from gall-nuts, is generally known as *gallotannic acid,* $C_{27}H_{22}O_{17}$. It has an intensely astringent taste, reddens litmus-paper, and is very soluble in water. When a solution of gallotannic acid is mixed with a solution of a ferric compound, it produces a deep bluish-black precipitate, which is the basis of writing-ink. The gradual darkening of pale, watery ink is due to the oxidation of the iron it contains. Tannins form insoluble compounds with starch, gelatine, and other organic bodies, the most remarkable being those with gelatine, which form the basis of leather.

**554. Oxalic Acid,** $C_2H_2O_4$, is met with in the juice of the sorrel, rhubarb, and many plants, sometimes in the free state, but more frequently in the compound known as *calcic oxalate.* It is commonly prepared by the oxidation of sugar or starch with nitric acid: one part of sugar is dissolved in eight parts of nitric acid, and gently heated, when intense action ensues, with a copious disengagement of nitrous acid fumes. By evaporating the solution, oxalic acid may be obtained in large, transparent, and intensely sour crystals. Oxalic acid is poisonous, and its crystals resemble those of Epsom salts, for which it is sometimes mistaken. In cases of poisoning with it, chalk or magnesia, mixed in water, is the proper antidote. Oxalic acid is largely used in calico-printing; it is also employed as a delicate test for the presence of lime, with which it forms an insoluble salt. It removes ink and iron stains from linen by forming a soluble oxalate of iron, but the acid is so corrosive as to injure the fibre if not immediately removed by washing.

**555. Alkaline Organic Salts.**—The compounds of this group are derived from the organic acids by the substitution of a radicle of the Lithium group for the basic hydrogen of the acid. The most important salt of the acid series is hydro-potassic tartrate (cream of tartar), $(HK)$, $(C_4H_4O_4)O_2$. It is deposited in an impure state from wine constituting the tartar or argol of commerce. When purified by recrystallization, it forms a white crystalline powder, or larger crystals, soluble with difficulty in cold water, more readily in hot water, and possessing a pleasant sour taste. Among the salts of the neutral series, sodio-potassic tartrate (Rochelle salts), $(NaK)\ (C_4H_4O_4)\ O_2 + 4\ H_2O$, deserves special notice. It is obtained in beautiful large crystals, perfectly colorless when pure, of mild saline taste, by crystallizing mixed solutions of argol and soda-ash. It is largely used in medicine, forming the chief constituent of Seidlitz powders.

## § 2. *Organic Alkaloids.*

**556.** The term alkaloid has been applied to a large number of bodies having the general constitution of amines. They contain carbon, oxygen, hydrogen, and nitrogen, and act as bases. Many compounds analogous to these have been artificially prepared, but the vegetable alkaloids have as yet defied the constructive power of the chemist. They include some of our most violent poisons, and act powerfully on the animal economy. Most of the alkaloids dissolve sparingly in water, but freely in boiling alcohol; are intensely bitter, and usually restore the reddened color of litmus. They are the most powerful medicines and poisons known. Gallotannic acid precipitates most of the organic bases, forming, with them, insoluble compounds; hence it is an excellent antidote when they have been taken in poisonous doses. We shall notice only the more important alkaloids found in vegetable substances.

**557. Nicotine,** $C_{10}H_{14}N_2$.—This compound is of interest, as the chief alkaloid contained in the smoke of tobacco, and, in fact, is the proximate cause of the narcotic effects produced by the use of that plant, which contains it in quantities varying from two to eight per cent. It is a colorless, transparent oil, which boils at 250° C., giving off very irritating vapors. It is soluble in water, alcohol, and oils. It has a burning taste, even when much diluted, and is one of the most violent poisons known. The effect is said to be produced upon the motor nerves, producing convulsions, and afterward paralysis. Five milligrammes has been found sufficient to kill a medium-sized dog in three minutes.

**558. Morphine,** $C_{17}H_{19}O_3N$.—This is the chief active principle of opium, which is the hardened, milky juice of the poppy. Opium is a very complex body, containing, besides morphine, a large number of other alkaloids. *Morphine* (from Morpheus, in consequence of its sleep-inducing property) is a crystallizable, resin-like body, without odor, and possessing a bitter, disagreeable taste. It is a powerful narcotic and poison, and, in the form of the acetate, sulphate, and hydrochlorate, is largely used in medicine. *Piperine*, $C_{17}H_{19}NO_3$, is a substance isomeric with morphine, found in common black and white pepper. It is nearly insoluble in cold water, has an acrid taste, and, when acted upon by nitric acid, develops an odor of bitter-almonds. *Capsicine* is an alkaloid obtained from Cayenne pepper. It forms crystallizable salts, with acetic, nitric, and sulphuric acids.

**559. Strychnine,** $C_{21}H_{22}O_2N_2$, is chiefly obtained from the beans of the *strychnos nux-vomica*, a small East India tree, but is found in several other plants belonging to that tribe. Cold water dissolves only $\frac{1}{7000}$ of its weight of strychnine, but it is more readily soluble in essential oils and chloroform. From its solutions it crystallizes in small brilliant octahedrons, of exceedingly bitter taste. Such is its intense bitterness, that it imparts it perceptibly to 700,000 times its weight of water. It is a deadly poison, $\frac{1}{30}$ of a grain killing a dog in thirty seconds. It takes effect upon the nerve-centres of the spinal axis, producing fearful convulsions. The terrible *woorara* poison, with which the South American natives poison their arrows, and which has been lately used as a remedy for *tetanus*, appears to contain a principle nearly allied if not identical with strychnine. *Bracine* is an alkaloid closely allied to strychnine, and obtained from the same genus of plants.

**560. Quinine,** $C_{20}H_{24}O_2N_2$, is extracted from pulverized Peruvian bark by acidulated water. It is a white, crystalline substance, which unites with acids, producing intensely bitter salts. Quinine sulphate, which forms light, bulky crystals, is the salt employed in medicine. It dissolves sparingly in water, but freely in dilute sulphuric acid and alcohol. *Cinchonine* is another alkaloid from the same source.

**561. Caffeine Series.**—Two terms of this series are known. *Theobromine*, $C_7H_8O_2N_4$, is a crystalline alkaloid, obtained from cacao-beans, the source of chocolate. *Caffeine* or *theine*, $C_8H_{10}O_2N_4$, is an alkaloid, which may be obtained from coffee, tea, and several other plants, the stimulating effects of which are in part due to the presence of caffeine compounds. Coffee seldom contains more than one per cent. of the principle, while tea furnishes three or four. Caffeine crystallizes in long, flexible, silky needles, has a slightly bitter taste, and dissolves sparingly in cold water, but freely in hot water.

The stimulating effects of coffee and tea are, however, not due to the caffeine alone, but are modified by various other ingredients. In tea, the alkaloid is associated principally with tannin and an essential oil; in coffee, with empyreumatic and essential oils.

## § 3. *Albuminous Substances.*

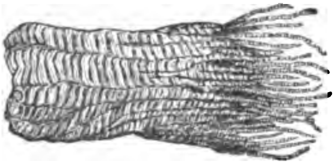
**562.** Under this head are classed a number of compounds, some of which form essential portions of the bodies of animals, and occur in certain parts of vegetables; while others, not properly albuminoids, are obtained, directly or indirectly, from the animal organism. The albuminoids possess constitutions very complicated, and our knowledge of their chemical relations is limited. They do not crystallize, but are found in amorphous, jelly-like form. They contain, in addition to carbon, oxygen, hydrogen, and nitrogen, small quantities of sulphur and phosphorus. Strong mineral acids dissolve all of the albuminoids.

**563. Albumen** is the chief and characteristic constituent of the serum of the blood, and of white of egg, and occurs in all the fluids which supply nutritive material for the renovation of the animal tissues. It forms about seven per cent. of blood, and twelve per cent. of the white of egg. Albumen exists in two modifications—the soluble form, and the insoluble variety into which it may be brought by the action of heat, as when white of egg is boiled. These two modifications are identical in chemical composition, and the difference is thought to be due to the presence of certain mineral salts which are associated with the soluble variety. A solution of albumen, heated to 72° C., is coagulated.

*Vegetable albumer* abounds in the juice of many soft, succulent plants used for food; it may be extracted from potatoes by macerating the sliced tubers in cold water containing a little sulphuric acid.

**564. Musculine** is the name given to the substance which forms the basis of muscular tissue. This occurs in bundles, as shown in Fig. 200, the parallel fibres having wrinkles or cross-markings. If a piece of lean beef be washed in clean water, its red color, which is due to blood, gradually disappears, leaving a whitish mass compcsed of musculine, and the areolar tissue which binds the fibres of the muscle together. Like albumen, it is capable of being converted into an insoluble body. *Fibrine* is a constituent of blood, forming in the healthy state about two parts in 1,000 parts of that liquid. The clotting of blood, when freshly drawn, is due to the coagulation of its fibrine, which solidifies into a net-work of fibres. Dilute solutions of potash and soda dissolve fibrine, as they do albumen. When wheat-flour is made into dough, and then kneaded on a sieve, or a piece of muslin under a stream of water, its starch is washed away, and there remains a gray, tough, elastic substance, almost resembling animal skin in appear-

FIG. 200.



Fibres of Lean Meat, magnified.

ance. When dried it has a glue-like aspect, and is therefore called *gluten.* The crude gluten thus prepared, when freed from oil, albumen, etc., proves to be identical with animal albumen.

The effect of boiling upon fibrine is to render it hard and tough. Heat, as we have seen, converts soluble into coagulated albumen which is insoluble in water, either hot or cold.

**565. Caseine** is an essential constituent of milk, existing in it to the extent of about three per cent., and forming its curd, or cheesy principle. In milk it is held in solution by the presence of a small portion of free alkali, and, when this is neutralized by an acid, the caseine is precipitated, or the milk *curdles.* By neutralizing the acid, the caseine is redissolved. Almonds, peas, beans, and many other seeds, contain an albuminoid closely resembling caseine, sometimes known as *legumine*, or vegetable caseine. This is not coagulable by heat, but by alcohol and acetic acid. The coagulated legumine resembles the curd of milk. The Chinese make a cheese from peas, which gradually acquires the smell and taste of milk-cheese.

*Milk* is a secretion of special interest from the circumstance that it constitutes the entire food of the young animal for some months, and consequently must contain all the elements necessary for the rapid development of the various tissues of the body. It has essentially the same constituents in carnivorous animals that it has in the herbivorous, although the proportions are somewhat variable. When examined under a microscope it is seen to consist of a transparent fluid, in which float transparent globules consisting of fat, surrounded by an envelope of albumen. When milk is allowed to remain at rest for a few hours, at the ordinary temperature of the air, the fat-globules rise to the surface; and, if the layer of cream thus formed be removed and subjected to mechanical action, the albuminous envelope is broken, and the globules of fat coalesce into a mass forming *butter*. Good milk, when perfectly fresh, is always feebly alkaline; when left to itself, however, it soon becomes sour, and is found to contain lactic acid. The quantity and quality of milk vary. We give below a statement of the composition of cow's-milk, from an analysis made by Haidlen:

| | |
|---|---|
| Water | 873.00 |
| Butter | 30.00 |
| Caseine | 48.20 |
| Milk-sugar | 43.90 |
| Calcic phosphate | 2.31 |
| Magnesic phosphate | 0.42 |
| Iron phosphate | 0.07 |
| Potassic chloride | 1.44 |
| Sodic chloride | 0.24 |
| Soda combined with caseine | 0.42 |
| | 1000.00 |

**566. Gelatine.**—Animal membranes, skin, tendons, and even bones, dissolve in water at a high temperature, more or less completely, but with very different degrees of facility, giving solutions which on cooling acquire a soft-solid, tremulous consistence. The substance so produced is called gelatine. It does not preëxist in the animal system, but is generated from the membranous tissue by the action of hot water. Cut into slices and exposed to a current of dry air, it shrinks much in volume, forming a transparent, glassy, brittle mass soluble in hot water. The aqueous solution is precipitated by alcohol, tannin-solution, and many other substances. Gelatine is largely employed as an article of food, and in manufactures as "size" and "glue." The cartilages of the joints, the cornea of the eye, and the ribs, yield a gelatine, called, by way of distinction, *chondrine*.

*Chitine*, $C_9H_{12}HO_6$, constitutes the skeletons of insects and crustacea. It is a white substance which retains the form of the texture from which it is obtained; the word *chitine* means a *mantle.*

**567. Urea,** $CH_4ON_2$, is one of the chief solid constituents of urine, from which it may be obtained. It is also produced by heating ammonic cyanate ($H_4N,CNO$), with which it is isomeric. Urea crystallizes in transparent colorless prisms soluble in water and alcohol. It is inodorous, and has a cooling, saline taste. By heat it is decomposed into ammonia, ammonic cyanate, and cyanuric acid. This compound is of special interest as the first organic compound artificially produced.

**568. Creatine,** $C_4H_{11}O_4N_3$.—Creatine occurs in the juice of flesh. When pure, it forms colorless brilliant prismatic crystals, readily soluble in hot water. The aqueous solution has a slightly bitter and acrid taste, and a neutral reaction. It forms no salts with acids. By the action of strong acids, it is converted into creatinine.

**569. Pepsine,** is a nitrogenous substance contained in the gastric juice, and has never been perfectly isolated. It is the active agent concerned in digestion. An artificial *gastric juice* which acts upon albuminoid substances is obtained by digesting the mucous membrane of the stomach (usually of a pig) with a warm, dilute solution of hydric chloride.

**570. Hæmoglobine,** also called *hœmato-crystalline,* is made up of carbon, hydrogen, iron, nitrogen, oxygen, and sulphur, and forms the chief part of the red globules of the blood of vertebrate animals. Usually it is amorphous, but from some animals it can be separated in crystalline form. Dilute solutions of this substance may be heated to 160° F. without marked change, but if the heat is continued the hæmoglobine is disorganized and splits up into *hœmatine,* $C_{96}H_{102}N_{12}Fe_3O_{18}$, and coagulated albumen. Alcohol also decomposes it.

**571. Putrefaction.**—The exact character of the fermentation which takes place when animal bodies putrefy is but little known. Among the products of these changes are hydrogen, nitrogen, carbonic dioxide, ammonia, hydrogen carbides, sulphides, and phosphides. The gaseous combinations of sulphur and phosphorus are the chief causes of the offensive odor of putrefying bodies. As the presence of moisture, a favoring temperature, and access of air, are essential conditions of putrefaction, if any of them are withdrawn, the effect is prevented. It is well known that the most perishable organic substances, both vegetable and animal, may be indefinitely preserved by drying. Cold checks decomposition, and it is entirely arrested by freezing. So, if the prime inciter of change, the air with its floating organic germs, is excluded, putrefaction cannot take place. This fact is illustrated by the general practice of preserving all kinds of alimentary substances, meat, fruits, and vegetables, in vessels which exclude the air. It is not enough, however, to exclude these agents from the surface of fermentable bodies, the germs which have already been absorbed must also be destroyed. This may be done by a sufficient elevation of temperature. In some cases boiling is effectual, in others a much higher temperature is required.

**572. Ferment-Diseases.**—The foul accumulations of neglected towns, and the decomposing organic matter of many swampy districts, give off invisible emanations known as *miasms* and *malaria*, which fill the air, and often occasion fatal epidemics. Of their composition, nature, or mode of action, nothing very definite is known, but it has been held that the effects produced by them are due to the presence of a large quantity of ferment-germs which, being inhaled, develop and induce a condition somewhat similar to fermentation in the living system. Intermittent fever, typhoid fever, and cholera, have been ascribed to this cause. Various other diseases, as small-pox, hydrophobia, etc., have also with much reason been considered as consisting in processes of fermentation running their course in the living organism.

# APPENDIX.

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## *The Metrical System of Weights and Measures.*

### LENGTH.

Kilometre = 1000 metres.
Hectometre = 100 "
Decametre = 10 "
**Metre** (m.) = 1 metre.
Decimetre = 0.1 "
Centimetre (cm.) = 0.01 "
Millimetre (mm.) = 0.001 "

### VOLUME.

Kilolitre = 1000 litres.
Hectolitre = 100 "
Decalitre = 10 "
**Litre** = 1 litre.
Decilitre = 0.1 "
Centilitre = 0.01 "
Millilitre (or cubic centimetre) (c. c.) = 0.001 "

### WEIGHT.

Kilogramme = 1000 grammes.
Hectogramme = 100 "
Decagramme = 10 "
**Gramme** (grm.) = 1 gramme.
Decigramme = 0.1 "
Centigramme = 0.01 "
Milligramme = 0.001 "

---

The metre = 39.368 inches.
The litre = 1.76 pints.
The gramme = 15.432 grains.

## *Relation of the Scales of the Centigrade and Fahrenheit Thermometers.*

| Cent. | Fahr. | Cent. | Fahr. | Cent. | Fahr. | Cent. | Fahr. |
|---|---|---|---|---|---|---|---|
| + 100 = | + 212 | + 64 = | + 147.2 | + 29 = | + 84.2 | − 6 = | + 21.2 |
| 99 = | 210.2 | 63 = | 145.4 | 28 = | 82.4 | 7 = | 19.4 |
| 98 = | 208.4 | 62 = | 143.6 | 27 = | 80.6 | 8 = | 17.6 |
| 97 = | 206.6 | 61 = | 141.8 | 26 = | 78.8 | 9 = | 15.8 |
| 96 = | 204.8 | 60 = | 140 | 25 = | 77 | 10 = | 14 |
| 95 = | 203 | 59 = | 138.2 | 24 = | 75.2 | 11 = | 12.2 |
| 94 = | 201.2 | 58 = | 136.4 | 23 = | 73.4 | 12 = | 10 4 |
| 93 = | 199.4 | 57 = | 134.6 | 22 = | 71.6 | 13 = | 8.6 |
| 92 = | 197.6 | 56 = | 132.8 | 21 = | 69.8 | 14 = | 6.8 |
| 91 = | 195.8 | 55 = | 131 | 20 = | 68 | 15 = | 5 |
| 90 = | 194 | 54 = | 129.2 | 19 = | 66.2 | 16 = | 3.2 |
| 89 = | 192.2 | 53 = | 127.4 | 18 = | 64 4 | 17 = | 1.4 |
| 88 = | 190.4 | 52 = | 125.6 | 17 = | 62.6 | 18 = | − 0.4 |
| 87 = | 188.6 | 51 = | 123.8 | 16 = | 60.8 | 19 = | 2.2 |
| 86 = | 186.8 | 50 = | 122 | 15 = | 59 | 20 = | 4 |
| 85 = | 185 | 49 = | 120.2 | 14 = | 57.2 | 21 = | 5.8 |
| 84 = | 183.2 | 48 = | 118.4 | 13 = | 55.4 | 22 = | 7.6 |
| 83 = | 181.4 | 47 = | 116.6 | 12 = | 53.6 | 23 = | 9.4 |
| 82 = | 179.6 | 46 = | 114.8 | 11 = | 51.8 | 24 = | 11.2 |
| 81 = | 177.8 | 45 = | 113 | 10 = | 50 | 25 = | 13 |
| 80 = | 176 | 44 = | 111.2 | 9 = | 48.2 | 26 = | 14.8 |
| 79 = | 174.2 | 43 = | 109.4 | 8 = | 46.4 | 27 = | 16.6 |
| 78 = | 172.4 | 42 = | 107.6 | 7 = | 44.6 | 28 = | 18.4 |
| 77 = | 170.6 | 41 = | 105.8 | 6 = | 42.8 | 29 = | 20.2 |
| 76 = | 168.8 | 40 = | 104 | 5 = | 41 | 30 = | 22 |
| 75 = | 167 | 39 = | 102.2 | 4 = | 39.2 | 31 = | 23.8 |
| 74 = | 165.2 | 38 = | 100.4 | 3 = | 37.4 | 32 = | 25.6 |
| 73 = | 163.4 | 37 = | 98.6 | 2 = | 35.6 | 33 = | 27.4 |
| 72 = | 161.6 | 36 = | 96.8 | 1 = | 33.8 | 34 = | 29.2 |
| 71 = | 159.8 | 35 = | 95 | 0 = | 32 | 35 = | 31 |
| 70 = | 158 | 34 = | 93 2 | − 1 = | 30.2 | 36 = | 32.8 |
| 69 = | 156.2 | 33 = | 91.4 | 2 = | 28.4 | 37 = | 34.6 |
| 68 = | 154.4 | 32 = | 89.6 | 3 = | 26.6 | 38 = | 36.4 |
| 67 = | 152.6 | 31 = | 87.8 | 4 = | 24.8 | 39 = | 38.2 |
| 66 = | 150.8 | 30 = | 86 | 5 = | 23 | 40 = | 40 |
| 65 = | 149 | | | | | | |

It is often necessary to convert temperatures expressed on the Fahrenheit scale into the corresponding temperatures on the Centigrade scale, and the following rules will assist the pupil in transforming one scale into the other:

(1.) *To convert Fahrenheit Degrees into Centigrade Degrees.*—Subtract 32 from the number of degrees, and multiply the remainder by $\frac{5}{9}$ (or 0.5).

(2.) *To convert Centigrade Degrees into Fahrenheit Degrees.*—Multiply the number of degrees by $\frac{9}{5}$ (or 1.8), and add 32 to the product.

## *Table for the Conversion of Grammes into Grains, Centimetres into Inches, and Litres into Quarts.*

| CONVERSION. | 1. | 2. | 3. | 4. | 5. |
|---|---|---|---|---|---|
| Grammes into Grains........ | 15.4346 | 30.8692 | 46.3038 | 61.7384 | 77.1730 |
| Centimetres into Inches...... | .3937079 | .7874158 | 1.1811237 | 1.5748316 | 1.9685395 |
| Litres into Imperial Quarts.. | 0.88066 | 1.76132 | 2.64198 | 3.52264 | 4.40330 |
| Litres into U. S. Quarts..... | 1.05708 | 2.11415 | 3.17123 | 4.22830 | 5.28538 |

## *Table of Elementary Atoms and Molecules.*

| NAMES OF PERISSAD ELEMENTS. | Symbols of Atoms. | Symbols of Molecules. | Quantivalence. | Atomic Weight. |
|---|---|---|---|---|
| Hydrogen ................ | H | H-H | I. | 1.0 |
| Fluorine.................. | Fl | F-F | I. | 19.0 |
| Chlorine.................. | Cl | Cl-Cl | I., III., V., VII. | 35.5 |
| Bromine ................ | Br | Br-Br | I., III., V., VII. | 80.0 |
| Iodine.................... | I | I-I | I., III., V., VII. | 127.0 |
| *Lithium* ................ | Li | Li-Li | I. | 7.0 |
| Sodium (*Natrium*)........ | Na | Na-Na | I., III. | 23.0 |
| Potassium (*Kalium*) ..... | K | K-K | I., III., V. | 39.1 |
| *Rubidium*............... | Rb | Rb-Rb | I. | 85.4 |
| *Cæsium*.................. | Cs | Cs-Cs | I. | 133.0 |
| Silver (*Argentum*)........ | Ag | Ag-Ag ? | I., III. | 108.0 |
| *Thallium* ................ | Tl | Tl-Tl ? | I., III. | 204.0 |
| Gold (*Aurum*)............ | Au | Au≡Au ? | I., III. | 197.0 |
| Boron..................... | B | B≡B ? | III. | 11.0 |
| Nitrogen.................. | N | N≡N | I., III., V. | 14.0 |
| Phosphorus.............. | P | $P_2$≣$P_2$ | I., III., V. | 31.0 |
| Arsenic .................. | As | $As_2$≣$As_2$ | I., III., V. | 75.0 |
| Antimony (*Stibium*)...... | Sb | $Sb_2$≣$Sb_2$ ? | III., V. | 122.0 |
| Bismuth.................. | Bi | $Bi_2$≣$Bi_2$ ? | III., V. | 210.0 |
| *Vanadium* .............. | Va | V≡V ? | III., V. | 51.37 |
| Uranium ................. | Ur | U≡U ? | III., V. | 120.0 |
| Columbium............... | Cb | Cb≣Cb ? | V. | 94.0 |
| Tantalum ................ | Ta | Ta≣Ta ? | V. | 182.0 |

| NAMES OF ARTIAD ELEMENTS. | Symbols of Atoms. | Symbols of Molecules. | Quantivalence. | Atomic Weight |
|---|---|---|---|---|
| Oxygen | O | O=O | II. | 16.0 |
| Sulphur | S | S=S | II., IV., VI. | 32.0 |
| *Selenium* | Se | Se=Se | II., IV., VI. | 79.4 |
| *Tellurium* | Te | Te=Te | II., IV., VI. | 128.0 |
| *Molybdenum* | Mo | Mo? | II., IV., VI. | 96.0 |
| Tungsten (*Wolfram*) | W | W? | IV., VI. | 184.0 |
| Copper (*Cuprum*) | Cu | Cu? | II. | 63.4 |
| Mercury (*Hydrargyrum*) | Hg | Hg | II. | 200.0 |
| Calcium | Ca | Ca? | II. | 40.0 |
| Strontium | Sr | Sr? | II., IV. | 87.6 |
| Barium | Ba | Ba? | II. | 137.0 |
| Lead (*Plumbum*) | Pb | Pb? | II., IV. | 207.0 |
| Magnesium | Mg | Mg? | II. | 24.0 |
| Zinc | Zn | Zn? | II. | 65.2 |
| *Indium* | In | In? | II., IV., VI. | 72.0 |
| Cadmium | Cd | Cd | II. | 112.0 |
| *Glucinum* | G | G? | II. | 9.3 |
| *Yttrium* | Y | Y? | II. | 61.7 |
| *Erbium* | E | E? | II. | 112.6 |
| *Cereum* | Ce | Ce? | II., IV. | 92.0 |
| *Lanthanum* | La | La? | II. | 93.6 |
| *Didymium* | D | D? | II. | 95.0 |
| Nickel | Ni | Ni? | II., IV. | 58.8 |
| Cobalt | Co | Co? | II., IV. | 58.8 |
| Manganese | Mn | Mn? | II., IV., VI. | 55.0 |
| Iron (*Ferrum*) | Fe | Fe? | II., IV., VI. | 56.0 |
| Chromium | Cr | Cr? | II., IV., VI. | 52.2 |
| Aluminium | Al | Al? | IV. | 27.4 |
| *Ruthenium* | Ru | Ru? | II., IV., VI. | 104.4 |
| *Osmium* | Os | Os? | II., IV., VI. | 199.2 |
| *Rhodium* | Ro | Ro? | II., IV., VI. | 104.4 |
| *Iridium* | Ir | Ir? | II., IV., VI. | 196.0 |
| *Palladium* | Pd | Pd? | II., IV. | 106.6 |
| Platinum | Pt | Pt? | II., IV. | 197.4 |
| Titanium | Ti | Ti? | II., IV. | 50.0 |
| Tin (*Stannum*) | Sn | Sn? | II., IV. | 118.0 |
| Zirconium | Zr | Zr? | IV. | 89.6 |
| *Thorium* | Th | Th? | II. | 115.72 |
| Silicon | Si | Si? | IV. | 28.0 |
| Carbon | C | C? | II., IV. | 12.0 |

## NOTE TO PAGE 91.

The views presented in the text concerning the distribution of the spectrum forces have long been regarded as established. But Dr. J. W. Draper maintains that, while the effects described are true as matters of observation, they are variously interpreted. He says that the accumulation of heat at one end of the spectrum is due to the same cause as the unequal spaces of the colors—that is, to the distorting action of the prism. With a diffraction spectrum produced by finely-ruled surfaces, he claims to have found, by many experiments, that the luminous spaces are equal; that, from the centre of the spectrum, near the sodium-line D, there are equal amounts of heat on the two sides; and, finally, that all the rings of the spectrum, irrespective of their color or wave-length, have equal heating-power.

# QUESTIONS.

## INTRODUCTION.

1. What is meant by the terms phenomena and order of Nature? 2. What purpose does *prevision* serve in science? 3. Define matter and force. 4. What are physical changes? 5. Give examples of chemical changes of matter. Give the distinction between compound and simple bodies. 6. Are the forces of Nature in any way connected?

## CHAPTER I.—Gravity.

7. Show how the processes of weighing and measuring are important to the chemist. What system of measurement is now in ordinary use? What is the metrical scale? 8. What is its basis? Describe this scale fully. 9. What is gravity? Give illustration showing mutual attraction of masses of matter. What relation exists between the quantity of matter and the force of gravity? 10. What is weight? 11. Describe the balance. 12. In what does the operation of weighing consist? 13. Give the unit of the French scale of weights. The gramme is equal to how many grains? 14. How may specific volumes be obtained? 15. How is volume related to weight? How is platinum related to hydrogen? What is specific gravity? 16. How is the specific gravity of solids heavier than water obtained? 17. How is the specific gravity of solids lighter than water obtained? 18. What precaution should be taken in finding the specific gravity of powdered solids? 19. How may the specific gravity of soluble solids be obtained? 20. How may the specific gravity of gases be obtained? 21. Explain the principle on which the hydrometer is constructed. 22. How does specific gravity afford means of identifying bodies? 23. Give distinction between specific gravity and density.

## CHAPTER II.—MOLECULAR ATTRACTIONS.

25. WHAT reason can be given for the conclusion that matter is universally porous? 27. What are atoms? How are they distinguished from molecules? 28. State what you can of the divisibility of matter? 29. Give distinction between adhesion and cohesion. 31. Explain conditions of "wetting." 32. What is capillary attraction? 33. What is said of reversed capillarity? 34. How may a gas be driven out from a solution? 35. How may insects walk upon water? 36. Explain what takes place in diffusion. 37. What principle explains the stability of our atmosphere? 38. What is the law of the diffusion of gases? 39. What is osmose? Explain Fig. 14. What occurs in atmospheric respiration? 40. May liquids and solids diffuse through gases? 42. What are diffusates? What are crystalloids and colloids? 43. Explain endosmose and exosmose. 44. What is the difference between absorption and osmose? 45. What is meant by the terms solution and solvent? 46. What conditions favor solution? 47. When is a liquid saturated? 48. How may solids be separated from solution? Give examples. 50. What is occlusion? 51. What are crystals? What are substances called which do not crystallize? 53. How may crystals be artificially produced? 54. What is mother-liquor? 55. What is said of crystals by fusion? 57. Does crystallization ever take place except in liquids? 58. State phenomena attending crystallization? 61. What forms do liquids tend to assume on crystallizing? 62. Crystals are solids of what class? 63. What are primary forms? What is a goniometer? 64. How many systems of crystallization are there? 65. Describe the monometric system. 66. How are the axes arranged in the dimetric system? 67. Give examples of, and describe, the trimetric system. 69. Give characteristics of rhombohedral and hexagonal systems. 71. What evidence is there that the axes of crystals are not mere imaginary lines? 72. What is cleavage? 73. What example of the derivation of form is given? 74. What is isomorphism? 75. What is dimorphism?

## CHAPTER III.—HEAT.

76. GIVE the term which is applied to the science of heat. 77. What is the general effect of heat upon matter? 78. How may the cohesion of a solid be overcome? 79. May gases be expanded indefinitely? 80. What do thermometers measure? 81. What advantages has mercury as a thermometric fluid? 82. Give the different thermometers in use, and state the peculiarity of each. 83. How is heat transferred? What are the best conductors? 84. Does heat travel with more facil-

**ity across the axis than in other directions? 85. Why do some substances feel so much warmer than others? 86. Explain what takes place when gases and liquids are heated. 87. What is radiation? How may equilibrium of temperature be obtained? 88. What effect does surface have on radiation? 89. What substances are good absorbers of heat? 90. What is dew? 91. What two kinds of radiant heat are there? 92 Define the terms diathermic and athermic. 93. How does the aqueous vapor affect the temperature of the earth? 94. What is the melting-point of a substance? 95. Give the distinction between latent heat and sensible heat. 96. What is sensible heat? 97. Explain how freezing is a warming process. 98. What is a freezing mixture? 99. Explain the process called "boiling." 100. What circumstances affect the boiling-point? 101. What is the spheroidal state? 102. What substances vaporize readily? 103. What becomes of the heat which has been consumed in converting liquids into vapors? 104. On reversing the process what occurs? 105. What is the effect of evaporation? 106. Explain the cryophorus. 107. How can the amount of atmospheric humidity be obtained? 108. Explain the hygrometer. 109. What relation is there between the vapor from a cubic inch of water, one of alcohol, and one of ether? 110. What is meant by elastic force? 111. Explain distillation, and give the meaning of the terms distillate and sublimate. 112. How may gases be reduced to liquid or solid conditions? 114. What is the difference between heat and cold? 115. Give an idea of the caloric hypothesis. 116. Give the facts which led to the new theory. 117. Heat is now how regarded? What is supposed to be true of the atoms? 118. What follows from this theory with regard to the temperature of bodies? 119. What is the *dynamical theory?* 120. What is combustion?**

## CHAPTER IV.—ELECTRICITY.

**121. STATE what is said of electricity? 122. What are conductors and insulators? 123. How do the electricities affect each other? 124. Explain the terms "charged" and "discharged." 125. What is the effect of bringing an excited glass tube near an electroscope? What is electrical induction? 126. Explain Fig. 48. 127. State Faraday's theory of induction. 128. What is a natural magnet? 129. What is the law of polarity? 130. Explain the term magnetic induction by reference to the figure. 131. What is the result of breaking a magnet? 132. What are those substances, which arrange themselves axially, called? 133. What is voltaic electricity, and whence the name? Describe the voltaic circuit. 134. What are the poles of the circuit? 135. How may the power of the circuit be increased? 136. How may increased**

effect, combined with steadiness of action, be secured? 137. Describe Daniell's battery. 138. Upon what does quantity of electricity depend? 139. Explain the principle of the Ruhmkorff coil. 140. Will voltaic electricity travel through air? 141. What is electrolysis? 142. Which bodies are termed electro-negative, which electro-positive? 143. Explain electro-gilding and electro-plating. 144. What relation exists between arrested electricity and heat? 145. Upon what do the degree and direction of the motion of the needle depend? 146. What is the astatic needle? 147. What is thermo-electricity?

## CHAPTER V.—LIGHT.

149. STATE what you can of light; give its velocity. 150. How is light affected by the prism? What is the order of refrangibility of the rays? 151. Give the wave-hypothesis. 152. What to the eye is the same as the gamut to the ear? How do the number of waves of red light compare with those of blue light in a given space? 153. What explanation is given of radiant heat? 154. What is interference? 155. Explain Fig. 70. The principle of interference leads to what conclusions regarding silence, darkness, etc.? 156. What happens when light is reflected at a certain angle? How may the change be detected? 157. In what other ways may light be polarized? 158. Show how the wave-theory explains polarization.

## CHAPTER VI.—CHEMISTRY OF LIGHT.

162. UPON what rays does the art of photography depend? 163. Describe Fig. 87, and state the facts regarding invisible radiations. 164. How do heat-rays, light-rays, and chemical rays, differ from each other? 165. What are actinometers? 166. What changes take place in the chemical activity of the solar rays, at different times of the day and year? 167. What is said of chemical action at the equator? 168. Where does the force which is most active in vegetative processes reside? 169. State the chemical effects of light? 170. What chemicals are employed in photography? 171. State how the invisible image is produced. 172. How is the invisible image brought out? 173. What are negatives and positives? 174. Give some idea of the varying effects of colored lights. 175. How is photography, in its applications, related to science?

## CHAPTER VII.—SPECTRUM ANALYSIS.

176. How is spectrum analysis related to other modern discoveries? 177. What is proved by recombining, by means of a lens, the

separated colored rays? 178. May the colors of the solar spectrum be still further decomposed? 179. What is said of the spectrum of the electric light? 180. What is dispersion? How does the dispersive power of flint-glass compare with that of crown-glass? 181. How may dispersion be increased? 182. When may four or five prisms be used to advantage? 183. Describe the spectroscope, and explain Figs. 100, 101, and 102. 187. What was Dr. Wollaston's discovery? 188. State what is said of Fraunhofer's lines. 189. Give the results of Dr. Draper's investigations. 190. How do the spectra of gaseous bodies differ from those of solids? What is the difference in the spectra of sodium and iron? 191. These spectral lines may serve as tests for what? 192. Increasing temperature and added pressure have what effect on the spectrum? 193. What are the spectrum-lines? 194. What relation exists between the dark solar lines and the bright lines produced by burning terrestrial substances? 195. What are absorption-lines? 196 What kind of light do vapors absorb? Explain Fig. 109. 197. What is meant by the reversal of the lines? Describe Fig. 110. 198. What principle of physics underlies the theory upon which spectrum analysis is based? 199. What clew is given us by Fraunhofer's lines? 200. Give illustrations showing the delicacy of spectrum analysis, when used as a means of testing chemical substances. 201. Mention the names of the new elements discovered by this means. 202. Explain use of spectroscope in steel-making. 203. Give organic indications of the spectroscope. 204. Give description of telespectroscope. 205. How does Prof. Young describe the red portion of the spectrum? 206. Describe the solar envelope. 207. What elements are found in the sun? 208. What evidence does spectrum analysis give us that stars are suns? 211. Give the spectroscopic proof of the motions of celestial bodies. 212. How does spectrum analysis prove the motions of the stars.

## CHAPTER VIII.—General Character of Chemical Action.

Give a general idea of chemical force. 216. Define analysis, proximate, ultimate, qualitative, and quantitative. 217. How do the effects of chemical force differ from those of the physical forces? 218. Why are some substances called elements, and others compounds? 220 How is chemical action affected by cohesion, heat, light, and electricity! 223. What is chemical induction? 224. When will nitrogen and hydrogen unite to form ammonia? 225. Define catalysis. 226. Is there any variation in the intensity of chemical action? 227. Has chemistry any mathematical basis? 228. Give the principle underlying the law of definitive proportions. 229. Explain the law of multiple proportions. 230. Give example of equivalent proportion.

## CHAPTER IX.—THEORETICAL CHEMISTRY.

231. GIVE an idea of the old atomic theory, and of the theory as revived by Dr. Dalton. 233. Define the term molecule as used by the physicist. 234. Define the term molecule as used by the chemist. 235. What is the ultimate unit of the chemist called? Define the terms analysis, synthesis, and metathesis. 236. What quantity of an element does the symbol represent?

237. What theory was first given in explanation of chemical changes? 238. Give a general idea of the binary theory. 239. What theory was the outgrowth of the binary theory? 240. Give a statement of the theory of types. 241. Do substitutions take place, atom for atom? 242. Define the term atomicity, and give groupings illustrating the subject. 243. What is quantivalence? How is it expressed? 244. What is the significance of bonds? 245. What relation exists between the number of bonds and the ability of the atoms to combine with each other? 246. To what is the term atomicity limited? 247. Define terms perissad and artiad. May a perissad ever become an artiad? 248. How is it supposed that changes of quantivalence may be explained? 249. When may an atom or molecule exist free? Does the quantivalence of a molecule depend upon the atomicity of its elements? 251. How may molecular chains be formed? 252. What are radicals? 253. Define compound radicals. 254. Can compound radicals exist free? 255. On what theory were acids, bases, and salts, formerly explained? 256. What is the relation of water to the acids and bases? 257. Give the constitution of the acids. 258. What is the constitution of a base? 259. Give formulas for acids, bases, and salts. 260. What are hydrates? 261. Is hydrogen an essential constituent of acids, bases, and salts? 262. What are ortho-acids and meta-acids? 263. What are normal salts? 264. Is common salt properly a salt? 265. Explain the constitution of the amides, amines, and alkalamides? 267. Show how the modern ideas of changes by substitution, types, atomicity, etc., are the result of investigations in organic chemistry. 268. What are the important organic elements? 268. What is the relation of carbon to organic chemistry? 269. How are isomeric phenomena explained? 270. When are compounds said to be polymeric? 271. Define allotropism. 272. Are molecules to be regarded as having dimensions? 273. What is the law of Avogadro? 274. What conclusion has been reached regarding the diameters of gaseous molecules? 275. Explain how the molecular weight of all aëriform bodies may be deter-

mined. 276. What is the standard of molecular weight? What is the crith? 277. How is atomic heat related to specific heat? 278. In what ratios do gases combine by volume?

## CHAPTER X.—The Chemical Nomenclature.

280. Show how the science of chemistry is reflected in the language. 281. How have the elements generally been named? What is the significance of the terminations *um* and *ine?* 282. What termination is given to the compound radicals? 283. In the naming of binary compounds which element is placed first? What change takes place in the termination of the positive element? What significance have the prefixes *hypo* and *per?* 284. Illustrate the use of numerical prefixes. 285. How are acids named? How salts? How bases? 286. Give examples of the names of amides, amines, and alkalamides? 287. Define empirical formula and rational formula. How are atomic groups separated? 288. In what form may chemical reactions be expressed?

## CHAPTER XI.—Hydrogen

289. What are the quantivalence and atomic weight of hydrogen? 290. What is the significance of the term hydrogen? 291. To what extent is hydrogen found in Nature? 292. In what different ways may hydrogen gas be obtained? 293. Describe a pneumatic trough. 294. Give properties of hydrogen. 295. How does hydrogen compare with other elements in weight? 296. What is known of its inflammability and explosiveness? 297. How may hydrogen be ignited without the application of heat? 298. What is occlusion?

## CHAPTER XII.—Chlorine, Fluorine, Bromine. Iodine.

299. Where is chlorine chiefly found? 300. How is the gas obtained? 301. What are the properties of chlorine? 302. Its uses? How does chlorine act as a bleaching agent? 303. What is the composition of muriatic acid? Give the reaction which takes place when sulphuric acid acts on sodic chloride. 305. How may chlorine combine with oxygen? 306. What use is made of chloric monoxide? 308. What are the properties of chloric acid? 309. Is fluorine found uncombined in Nature? 310. What is the distinguishing characteristic of hydric fluoride? 311. How is bromine obtained? 312. Give properties and uses of bromine. 313. What does the term iodine refer to? 314. What is the test for iodine? For what is iodine used? 315. When bromine and iodine are heated with hydrogen, what compounds are formed? 316. What can you say of the halogen group?

### CHAPTER XIII.—Sodium, Potassium, Lithium, Rubidium, Cæsium.

317. What was the first method of obtaining metallic sodium? 318. What is the chemical name of common salt? From what source is salt chiefly obtained? 320. Give uses of common salt. 321. How are sodic compounds distinguished from potassic compounds? What is the composition of sodic carbonate? 322. Give common name of hydrosodic carbonate. 323. How is caustic soda obtained? 324. What is the chemical name for Glauber's salt? 325. Give symbol of sodic nitrate. 326. How was potassium first obtained? 327. What takes place when potassium is thrown upon water? Why is this metal kept in naphtha? 329. Give the properties of potassic hydrate. 331. Where are the potassic salts found? What use has potassic carbonate? 332. How may hydro-potassic carbonate be formed? 333. Give common name for potassic nitrate. What is it used for? 334. Give composition of gunpowder. 335. What use has potassic chlorate in the laboratory? 336. What is soluble glass? 337. Describe the process of soap-making. Upon what does the consistence of the soap depend? 338. How does soap act in cleansing? 339. What elements are found associated with sodium and potassium? Where is rubidium found? What does the word cæsium mean?

### CHAPTER XIV.—Silver, Gold, Boron.

340. What is silver associated with? 341. Give its properties and uses. 342. What is the common name of argentic chloride? 344. Give composition of lunar caustic. How may the stains of indelible ink be removed? 345. What is the method employed to separate gold from its ores? 346. How does gold compare with other metals in malleability and ductility? What is aqua regia? 347. What does one modification of boron resemble? 348. Where is boric acid found? 349. What is borax? What property renders borax a valuable reagent?

### CHAPTER XV.—Nitrogen, Phosphorus, Arsenic, Antimony, Bismuth.

350. How is nitrogen obtained? 352. For what is nitrogen remarkable? 353. Give the composition and method of obtaining ammonia. 354. Why was it called spirits of hartshorn? 356. Nitrogen combines with oxygen forming what compounds? 357. What is laughing gas? 358. What effect is produced on the nervous system by nitric monoxide? 359. Give composition of nitric acid. 360. Its properties and uses. 362. When hydric chloride and ammonia are brought together, what substance is formed? Give the equation which expresses the reaction when ammonic chloride is formed. 363. How is ammonic hydrate

formed? Describe Woulfe's bottles. What atomic group resembles potassium? 366. What are the sources of phosphorus in Nature? 367. What is the molecular symbol of ordinary phosphorus? 368. Give the properties of this element. 369. How may red phosphorus be obtained? 370. Name the compounds of phosphorus and hydrogen. What takes place when calcic phosphide is thrown into water? 371. How does phosphoric pentoxide behave when it is brought in contact with water? 372. Describe arsenic. 373. To the formation of what gas is the detection of arsenic, by Marsh's test, due? How may the presence of antimony be distinguished from that of arsenic? 374. What is the composition of ratsbane? 375, 376. Give the characteristics of antimony and bismuth. What are the uses of bismuth?

## CHAPTER XVI.—OXYGEN.

377. GIVE the quantivalence of oxygen. State what you can of the modifications of oxygen. 378. What does the word oxygen mean? 380. To what extent is it distributed in Nature? 381. From what substances can oxygen be obtained? 382. Give properties of oxygen. 383. What effect has oxygen on combustion? 385. Under what conditions may iron wire or a steel spring be made to burn with brilliancy? 385. What is the cause of decay in animal and vegetable substances? 386. How is oxygen related to the vital processes? 387. How is ozone different from oxygen? 389. What can be said of autozone? Give formulas illustrating the three forms of oxygen. 390. What is the common name of hydric oxide? 391. When hydrogen is burned with oxygen, what is the product? 392. In what two ways may the composition of water be demonstrated? 393. Give properties of water. 394. Describe the forms which are the result of freezing water. 395. What is said of the unequal expansion of water? 396. Is there any relation existing between specific heat of water and climate? 397. What can be said of the solvent power of water? 398. How may water be purified? 400. Give the chemical properties of water. 401. State what you can of hydric dioxide. 402. What is known of the composition of the atmosphere? What considerations lead us to the conclusion that the atmosphere is a mixture of gases? 403, 404. Are the watery vapor and carbonic acid present in the atmosphere a constant quantity? 405. What office does oxygen perform in the atmosphere? What nitrogen?

## CHAPTER XVII.—SULPHUR, SELENIUM, TELLURIUM.

STATE the quantivalence of sulphur. 407. Describe modifications of sulphur. 408. How is the ordinary form obtained? 410. Under what conditions will ordinary sulphur pass into the other forms? 411. Of what use is plastic sulphur in the arts? 412. Where is hydric sulphide found? 413. Explain the method of liberating hydric sulphide? 414. Of what use is chloric disulphide in the arts? 415. How may sulphur unite with oxygen? 416. When is sulphurous oxide liberated? 417. For what is $SO_2$ used? 418. How may the sulphites be obtained? 419. Give composition of sulphuric oxide. 420. How early was sulphuric acid known? How is it prepared? 422. What are the properties of this acid? State phenomena which occur when sulphuric acid and water are mixed together. What can you state of disulphuric acid? 424. What do the words selenium and tellurium mean?

## CHAPTER XVIII.—Copper and Mercury.

425. From what ores is copper obtained? What are the properties of metallic copper? What is verdigris? What salts should be avoided in the culinary department? 426. Give preparation and uses of cupric oxide. Give common names for cupric sulphate and cupric arsenite. 427. State the properties and uses of mercury. What are amalgams? 428. What use did Priestley and Lavoisier make of mercuric oxide. 429. What is the antidote for mercuric chloride? 430. Give properties of calomel. 431. Under what name is mercuric sulphide sold?

## CHAPTER XIX.—Calcium, Strontium, Barium, Lead.

432. Where is calcium found? 433. How is lime obtained? 434. Describe the process of *slacking*. What is milk of lime? Give properties of calcic hydrate. 435. Of what is the best mortar made? To what is the hardening of the mortar supposed to be due? 436. What is bleaching-powder? 437. Give composition of gypsum. Give its uses. 438. What is the source of calcic carbonate? What is hard water? 439. Through what mutations does calcic phosphate pass? 440. Give properties of strontium and barium. What is the test for sulphuric acid? What are the uses of nitrate of strontium and baric sulphate? 441. What is galena? Give the uses of lead. What danger may arise from the use of lead pipe? The presence of what salts in the water protects the lead against its corroding action? 442. Give composition of plumbic monoxide and tetroxide. 443. How is white lead obtained? 444. Give properties of plumbic acetate.

## CHAPTER XX.—Magnesium, Zinc, Cadmium.

445. Where does magnesium occur? Of what use is it in the arts?

446. What are the common names of magnesic oxide and sulphate? 447. How is zinc obtained? Give properties. 448. State symbols for zincic oxide, chloride, and sulphate. Give common name of zincic sulphate. 449. Describe cadmium.

## CHAPTER XXI.—IRON, MANGANESE, NICKEL, AND COBALT.

450. GIVE history and occurrence of iron. 451. Describe the process of obtaining wrought-iron from cast-iron. 452. Give properties of iron. What is the effect of constant jarring on wrought-iron? 453. What is welding? What quality belongs only to iron, platinum, and sodium? 455. How is cast-iron obtained from the ore? 456. Give the origin of the term pig-iron. 457. Properties of cast-iron. 458. What is steel? How produced? Describe the Bessemer process. 459. What quality renders steel valuable in the arts? 460. State uses of ferrous oxide. 461. Which is the most valuable iron-ore? 462. What is the scientific name of iron pyrites? 463. Give uses and composition of green vitriol. 464. State what you can of manganese. 465. How are nickel and cobalt related?

## CHAPTER XXII.—CHROMIUM, ALUMINIUM, AND PLATINUM.

466. FOR what are the compounds of chromium used? 467. Give composition of dichromic trioxide and chromic trioxide. 468. Give history and properties of aluminium. Its uses. 469. What compound gives color to the ruby and sapphire? What are emery and corundum? 470. What constitutes the basis of pottery? 471. How is porcelain made? What gives color to common red pottery-ware? 472. Give properties of alum. What is the difference between alum burnt and unburnt? 473. What are the associates of platinum? What acid acts upon platinum? What power has spongy platinum? Its uses, in the arts. 474. How may platinic tetrachloride be obtained?

## CHAPTER XXIII.—TIN, SILICON.

475. WHICH is harder, gold or tin? What is the cause of the peculiar crackling sound given by tin when bent? 476. What is Britannia metal? What elements are allied to tin? 477. What three different modifications has silicon? 478. Give composition of silica. It forms the bulk of what minerals? 479. What is the composition of the *opal?* 480. When hydric fluoride acts upon silica, what gas is produced? 481. What is glass? How colored? 482. State how the different varieties of glass are produced.

## CHAPTER XXIV.—CARBON.

483. WHAT are the allotropic forms of carbon? Which is the purest form? State what you can of the diamond. 484. Give the properties of graphite. 485. How is charcoal obtained? 486. Its uses. Is it an antiseptic? What is lamp-black? 487. How is carbonic monoxide produced? What is the character of its flame? 488. Give composition of carbonic monoxide. 489. How is carbonic acid prepared? 490. How can you prove that $CO_2$ is not a supporter of combustion, and that it is heavier than air? What experiment shows that carbonic dioxide is in the expired breath? 491. What is soda-water? 492. Give properties and uses of carbonic disulphide. 493. What is the symbol of cyanogen? 494. Where is prussic acid found? 495. Describe potassic cyanide. 496. What is the popular meaning of combustion? How does the chemist use the term? 497. State what is said of the gradation of affinities between oxygen and the elements of combustible bodies. 498. Show how explosive combustion takes place. 499. What is *eremacausis?* 500. What does intensity of heat depend upon? 501. How does chemical action produce heat? 502. What kind of substances produce flame? State the conditions of illumination. 503. Describe the compound blow-pipe. 504. What constitutes the Drummond light? 505. How does the candle burn? 506. Give a statement of the structure of flame. 507. How may the constant presence of free carbon in the flame be proved? 508. Upon what does the amount of light produced depend? 509. What is the principle on which the safety-lamp is constructed?

## CHAPTER XXV.—HYDROCARBONS AND THEIR DERIVATIVES.

510. GIVE the composition of the hydrocarbons? Describe marsh-gas? Where is rock-oil found? 511. What is ordinary "kerosene?" When is it safe to use a paraffin-oil? For what is paraffin used? 512. Describe ethylene. What is illuminating gas? 513. Why is acetylene of special interest? 514. To what series do the *terpenes* belong? What are the oils of lemon and orange? 515. Give the properties of benzene. What compound is a stepping-stone to the production of aniline? What use is made of aniline? What other coloring substances are mentioned? 516. Give the general composition of the alcohols. From what is wood-spirit obtained? 517. Give formula for common alcohol. Its properties. 518. What is fusel-oil? 519. When is wine said to be sparkling? 520. Give what information you can regarding lager-beer, ale, and porter. 521. How does brandy differ from wine? 522. Give the composition of phenol. Mention substances valu-

able as antiseptics. 523. What is the composition of the fats and oils? For what is glycerine used? 524. How is nitro-glycerine exploded? 525. Mention some of the carbo-hydrates. What are the glucoses? 526. Give formula and properties of cane-sugar. 528. What is lactose used for? 529. Mention some substances having the composition $C_{12}H_{22}O_{11}$. What is varnish? 530. How does starch differ from sugar in its composition? 531. What are the properties and uses of starch? 532. How may commercial starch be converted into dextrine? Mention substances isomeric with starch. 533. From what may cellulose be obtained? 534. Give the uses of cellulose. 535. How may cellulose be converted into pyroxylene? How does the explosive force of pyroxylene compare with that of gunpowder? What is collodion? 536. What distinction is made between the terms fermentation and putrefaction? What is the exciting cause of fermentation? 537. Give examples of *ferments* and *fermentable bodies*. What is said of yeast? Mention different modes of fermentation. 538. What are the products of vinous fermentation? 539. How is *diastase* formed? 540. To what does vinous fermentation, if not checked, pass? What other name has vinegar? 541. How are ethers regarded by the chemist? Describe sulphuric ether. 542. How are aldehydes related to acids and alcohols? What are the properties of acetic aldehyde? 543. From what is camphor obtained? 544. Give composition and properties of chloral. 545. What are anæsthetics? What important representative of this class have we?

## CHAPTER XXVI.—ORGANIC CHEMISTRY. (*Continued.*)

546. FROM what is formic acid obtained? 547. What is the composition of acetic acid? 548. Give method of preparing butyric acid, and its properties. Where is glycocholic acid found? 549. What can be said of lactic acid and succinic acid? Where is malic acid found? What are the uses of tartaric acid? 550. Give composition of benzoic acid. 551. Give history of salicylic acid. 552. What is the acid obtained from the fruits of the orange family called? For what purposes is gallic acid used? 553. What is the distinguishing characteristic of tannic acids? What is the basis of writing-ink? 554. Give the antidote for oxalic acid. Its uses. 555. What can be said of Rochelle salts and cream-of-tartar? 556. Have the organic alkaloids been artificially produced? What substance precipitates the organic bases? 557. Give the name of the alkaloid contained in tobacco. 558. What narcotic is the active principle of opium? 559. From what is strychnine obtained? How does this alkaloid affect the nervous system? 560. What organic bases are obtained from Peruvian bark? 561. To what are the stimulating effects of tea and coffee due? 562. Describe

the albuminoids. 563. Where is albumen found? In what two modifications does it exist? 564. What is said of musculine, fibrine, and gluten? 565. Give the essential constituent of milk. What is said of the constitution of cow's milk? 566. What use is made of gelatine? From what is chitine obtained? 567. What was the first organic compound artificially produced? 568. Give the name of the compound occurring in the juice of flesh. 569. Has pepsine ever been perfectly isolated? 570. What constitutes the chief part of the red globules of the blood? 571. What are some of the products of putrefactive changes? How may putrefaction be prevented? 572. What is said of *ferment* diseases?

# PRONUNCIATION OF SOME TECHNICAL WORDS AND PROPER NAMES USED IN THIS WORK.

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## TECHNICAL WORDS.

Aç′-e-tate.
A-cet′-ic.
A-ce′-tous.
A-cet′-y-lene.
Al-bu′-men.
Al′-de-hyde.
Al-iz′-arĭne.
Al-kal′-am-ĭde.
Al-lo-trop′-ic.
Al-lot′-ro-pism.
Al-u′-min-a.
Al-u′-min-ic.
Al-u-min′-i-um.
Am′-ad-in.
Am′-ĭde.
Am′-ĭne.
Am-mo′-nic.
Am-yl′-ic.
An-æs-thet′-ics.
An′-il-ĭne.
Ant′-o-zone.
Ar′-ab-in.
Ar-gen′-tic.
Ar′-sen-ic (*noun*).
Ar-sen′-ic (*adj.*).
A-ther′-mic.
A-tom′-ic.
At-om-iç′-it-y.
Ben-zo′-ic.
Bo-raç′-ic.
Bro′-mĭne.
Bu-tyr′-ic.
Caf-fē′-ĭne.
Cam′-er-a ob-scu′-ra.
Caoutchouc (*Koo′-chook*)
Cap′-il-la-ry.
Cap′-si-cĭne.
Chitine (*ki′-teen*).
Chlorine (*Klo′-rin*).
Co′-balt.
Col-li-ma′-tor.
Col-loid′.
Cry-oph′-o-rus.
Di-al′-y-sis.
Di′-as-tase.
Di-a-ther′-man-cy.
Dif-fu′-sate.
Dy-ad′-ic.
E-lec-trol′-y-sis.
Er-e-ma-cau′-sis.
Eth′-yl.
Eth′-yl-ene.
Flu′-o-rĭne.
Gly̆ç′-e-rĭne.
Gly-co-chol′-ic (*kol*).
Gly′-co-gen.
Go-ni-om′-e-ter.
Hæ-mo-glo′-bĭne.
Hep′-tad.
Hip-pu′-ric.
Ho-mœ-o-mor′-phous.
Hy-draç′-id.
Hy-drox′-yl.
I′-o-dĭne.
I-som′-er-ides.
I-som′-er-ism.
I-so-mor′-phism.
Læv′-u-lose.
Lith′-arge.
Lith′-i-um.
Mer-cu′-ric
Mer′-cu-rous.
Met-ath′-e-sis.
Meth′-yl.

Mol′-e-cule.
Mon-ad′-ic.
Mor′-phĭne.
Mo-lyb-de′-num.
Nic′-o-tĭne.
Ni-trog′-e-nous.
Ni′-tryl.
O-le-fi′-ant.
Par′-af-fin.
Per-is′-sad.
Phe′-nyl.
Phos-phor′-ic.
Pho′-to-sphere.
Pip′-er-ĭne.
Plat-in′-ic.
Plat′-i-num.
Py-ri′-tes.
Py̆r-o-gal′-lic.
Quan-tiv′-a-lence.
Quinine (*Kwe-nīne′*, or *Kwin′-in*).
Saccharine (*Sak′-a-rin*).
Sa-li-cy̆l′-ic.
Sa-li′-va.
Sel′-e-nite.
Se-le′-ni-um.
Sil-iç′-ic.
Sil′-ic-on.
Spec′-tro-scope.
Spiegeleisen (*Spe′-ghel-i-sen*).
Sta-lac′-tite.
Sta-lag-mite.
Ste′-ar-ĭne.
Strychnine (*Strik′-nin*).
Suc-çin′-ic.
Sul-phu′-ric.
Sul′-phur-ous.
Tar-tar′-ic.
Tet′-rad.
The′-ine.
Ther-mot′-ic.
Tho-ri′-num.
Tourmaline (*Toor′-ma-lin*).
U-niv′-a-lent.
U′-re-a.

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## PROPER NAMES.

Al-deb′-a-ran.
Ampère (*Ang-pāre′*).
A-vo-gad′-ro.
Berthelot (*Ber′-tel-o*).
Bes′-sem-er
Bournon (*Boor′-nong*).
Bunsen (*Boon′-sen*).
Chaptal (*Shap′-tal*).
Clausius (*Clow′-si-us*).
Daguerre (*Dag-yair′*).
De la Rive (*Reeve*).
Descartes (*Day-cart′*).
Du Bois-Reymond (*Du-bwâ-Ray′-mong*).
Dumas (*Du-mah′*).
Durkheim (*Door′-kime*).
Dutrochet (*Du-tro′-shay*).
Ehrenberg (*A′-ren-berg*).
Fraunhofer (*Frown′-ho-fer*).
Galvani (*Gal-vah′-nee*).
Gay-Lussac (*Gah′-ee-lüs′-sac*).
Gerhardt (*Gair′-hart*).
Haidlen (*Hīde-len*).
Hauy (*Ah′-ü-y*).
Joule (*Jole*).
Kirchhoff (*Keerk′-hoff*).
Klaproth (*Klap′-rote*).
Leverrier (*Le-ver′-re-ā*).
Leyden (*Li′-den*).
Liebig (*Lee′-big*).
Marignac (*Mar-in′-yac*).
Matteucci (*Mat-tu′-tshee*).
Mayer (*My′-er*).
Montgolfier (*Mong-gol′-fee-ā*).
Oersted (*Ur′-sted*).
Par-a-cel′-sus.
Réaumur (*Ray′-o-mür*).
Regnault (*Rain′-yole*).
Ruhmkorff (*Room′-korf*)
Scheele (*Shay′-lay*).
Schellen (*Shel′-len*).
Schönbein (*Shane′-bine*).
Vogel (*Fo′-ghel*).
Wöhler (*Vail′-er*).

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